

## Foreword

*EVA Description and Design Criteria* is intended to provide an authoritative source of information and requirements for organizations involved in designing and planning payload EVA operations. The document is divided into two parts.

Part I contains descriptive information regarding the STS EVA capabilities and constraints, as well as guidelines for incorporating EVA design requirements and for integrating EVA into payload planning activities.

Part II of this document contains specific, technical design criteria for EVA tasks, and constitutes the EVA design reference for STS users.

  
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**Part I**  
**EVA Provisions, Capabilities, and Constraints**





## Part I

# EVA Provisions, Capabilities, and Constraints

### 1.0 INTRODUCTION AND DEFINITIONS

#### 1.1 Background of STS Extravehicular Activity

The Space Transportation System (STS) operational era offers numerous services to payload disciplines in addition to providing payload transportation to and from orbit and supplying an orbital operations platform. One such service is the capability to conduct extravehicular activity (EVA) for both payload and Orbiter operations. EVA involves all activities in space in which the crewmembers don space suits and life support systems and perform operations outside the pressurized, habitable environment of the Orbiter.

The EVA that was first performed by the late Ed White during the Gemini IV mission (fig. I.1-1) represented the United States' initial efforts toward attaining the capability to conduct exploration of the lunar surface in the Apollo Program which was to follow. The learning process associated with qualifying EVA as an operational technique forced development in areas of space suits and independent life support systems. Equally as significant were the lessons learned about the importance of body restraints, adequate man/machine interfaces, workload planning, simulation, and training.

The spectacular successes of the Apollo Program vividly demonstrated how man's natural capabilities as observer, explorer, mechanic, builder, and scientist can be utilized when extended beyond the confines of his space vehicle (fig. I.1-2). The application of EVA techniques to planned mission objectives is one thing. The extension of this capability to unscheduled maintenance and repair operations is something else again, and, as demonstrated in Skylab, it can result in significant con-

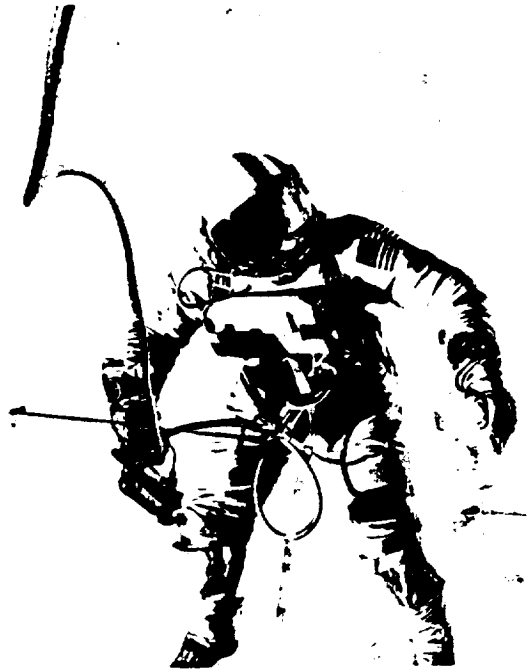


FIGURE I.1-1.— Gemini IV—first EVA.

tribution to the program and its scientific return (fig. I.1-3).

Shuttle extravehicular (EV) provisions and some basic carry-on equipment required for EVA are baselined for each Shuttle orbital mission. This accommodation is the result of program requirements to provide EVA capability on every flight for Orbiter contingencies, for crew rescue from a disabled Orbiter, and for Orbiter in-flight inspection. In the absence of a rescuing vehicle, EVA will provide the crew with some autonomous repair capability. In addition to these mandatory Shuttle EVA provisions and crew equipment, consumables

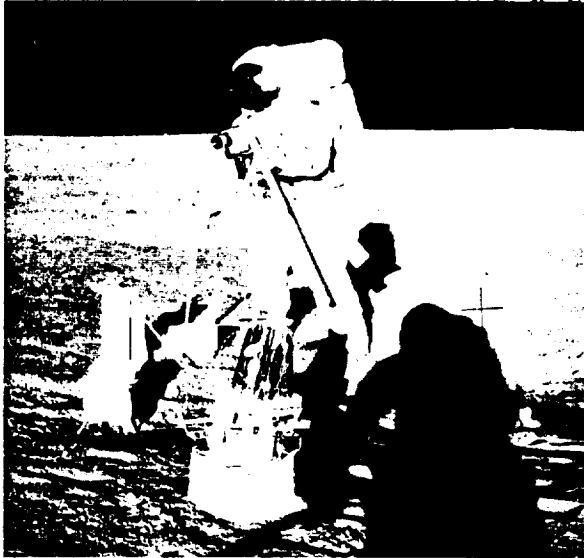


FIGURE I.1-2.— Apollo 12 lunar surface EVA.

and expendables are provided for three two-man EVA's on each mission.

When properly designed, considerable operational flexibility and mission-enhancement capability is provided, as our space-flight experience has proven. The following tasks are selected to represent the wide range of EVA applications for payload support.

- Inspection, photography, and possible manual override of payload systems and mechanisms (fig. I.1-4)
- Installation, removal, and transfer of film cassettes, material samples, and instrumentation
- Operation of equipment, including standard or special tools, cameras, and cleaning devices
- Cleaning of optical surfaces
- Connection, disconnection, and stowage of fluid and electrical umbilicals when safed
- Replacement and inspection of modular equipment and instrumentation on the payload or spacecraft
- Remedial repair and repositioning of antennas and solar arrays

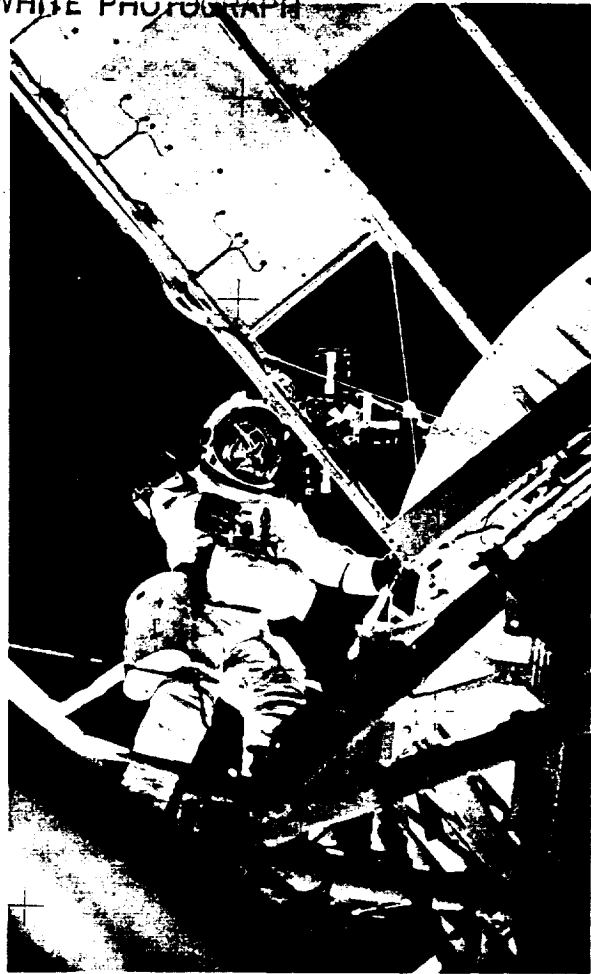


FIGURE I.1-3.— Skylab EVA.

- Activating/deactivating or conducting extravehicular experiments
- Providing mobility outside the cargo bay and in the vicinity of the Orbiter using manned maneuvering units (MMU's)
- Mechanical extension/retraction/jettison of experiment booms
- Removal/reinstallation of protective covers or launch tiedowns
- Transfer of cargo
- Large space station construction
- On-orbit satellite servicing



FIGURE I.1-4.— Apollo 9 EVA.

## 1.2 Purpose of This Document

The document describes the baselined Orbiter EVA provisions and carry-on equipment and the numerous factors associated with their use in sufficient detail to give the user an understanding of their capabilities and limitations. It also provides guidelines and techniques for implementing the design requirements of Part II in a manner most likely to result in simple, safe EVA tasks with high probability of success. Section 6 outlines the user and STS responsibilities in the payload integration process as they relate to EVA and describes how NASA standard and optional services can be used in a planned interaction to fulfill the requirements

for safety, flight planning, procedures development, and crew training. Finally, overviews of some baselined EVA's are presented to illustrate applications of the guidelines in this document.

## 1.3 Definitions

EVA is the term used to describe activities performed by the crewmember outside the pressurized spacecraft environment. Intravehicular activities (IVA's) are activities that take place in the cabin of the Orbiter or the Spacelab in a shirt-sleeve environment.

There are two basic classes of EVA, defined as follows.

- **Planned EVA** — tasks included in the nominal mission time line to support selected Shuttle or payload operations
- **Unscheduled EVA** — an EVA task not included in the scheduled mission activities but which may be required to achieve payload operation success, to enhance overall mission success, or to repair or override failed Orbiter or payload systems

There are two other important characteristics of EVA tasks which are used to define design and training requirements:

- **Criticality** — An EVA task will be placed in one of three categories: mission enhancement, mission success, or safety critical.
- **Complexity** — An EVA task may be classified as simple, intermediate, or complex.

Although classed as unscheduled, safety-critical EVA's by the above definitions, the term contingency EVA specifically refers to those EVA's necessary to effect the safe return of the Orbiter and crew.

These categories and their implications for EVA design will be further discussed in Section 5.

## 2.0 THE EXTRAVEHICULAR MOBILITY UNIT

The EMU (fig. I.2-1) is an independent anthropomorphic system that provides environmental protection, mobility, life support, and communications for the Shuttle crewmember to perform EVA in Earth orbit. Two EMU's are included in each baseline Orbiter mission, and consumables are provided for three two-man, 6-hour EVA's. Two EVA's are available for payload use, and the third is reserved for Orbiter unscheduled safety-critical EVA. Additional EVA's may be supported by Orbiter consumable kits to support EMU resupplying and airlock repressurization cycles.

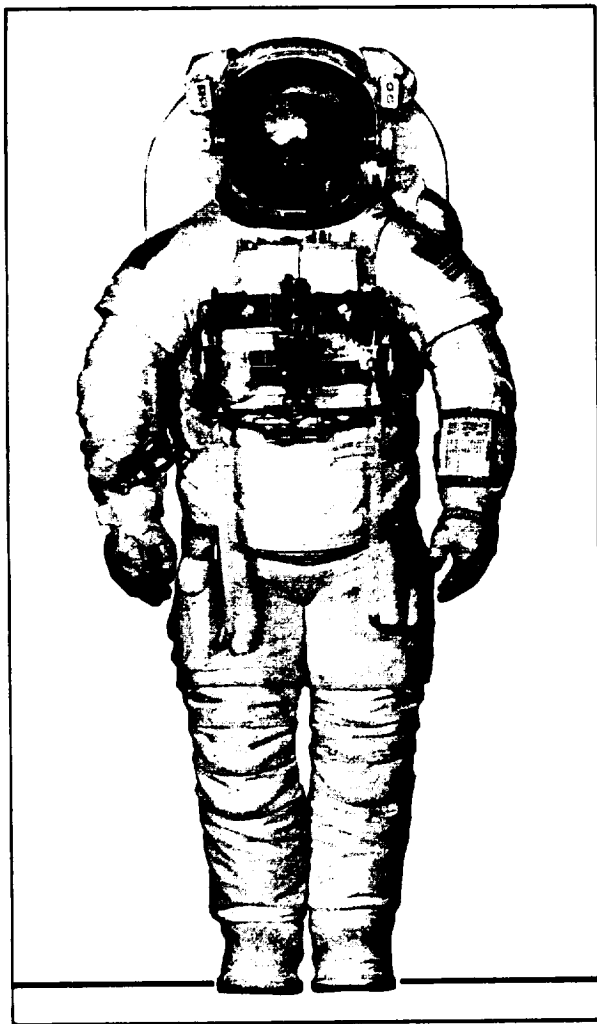


FIGURE I.2-1.— The extravehicular mobility unit.

Though similar in design and capabilities to those used during Apollo and Skylab, the Shuttle EMU emphasizes improved reliability with minimum maintenance and pre-EVA checkout requirements. Customized suit fitting requirements have been reduced through the use of standard-sized components that combine with interchangeable sizing elements to fit a full range of crewmembers.

The EMU consists of a space suit assembly that includes the basic pressure-garment components, a primary life support system (PLSS), a backup life support system for emergency use, an ultrahigh-frequency (UHF) radio communication system, and the displays and controls required to operate them (fig. I.2-2). The weight of the charged EMU is 117 kilograms (257 pounds).

The PLSS consumables are supplied in sufficient quantity to provide 7 hours of independent life support, only 6 hours of which are available for nominal EVA's. The remaining hour is apportioned for pre- and post-EVA overhead and a one-half-hour reserve. Actual use rates of oxygen, water, and lithium hydroxide are functions of each crewmember's metabolic rate, which, in turn, depends on his workload and other physiological factors. Consumption of electrical power is relatively constant. When proper consideration is given to workload planning, crewman restraint at the worksite, and adequate crew training, there is little probability of exceeding the capacity of the Shuttle EMU during a 6-hour EVA.

The backup life support provided by the secondary oxygen pack (SOP) consists of open-loop ventilation at a reduced suit pressure and is limited to 30 minutes. Unlike the PLSS, the SOP cannot be resupplyed on orbit.

The EMU caution and warning system monitors system configuration, environmental parameters, and consumables status. When detected, faults are displayed to the crewman automatically, along with the corrective action, and the crewman can display suit parameters and consumables status at any time. The Shuttle EMU is thus independent of ground monitoring and control. Crew health and workload are monitored via real-time transmission of EKG data.

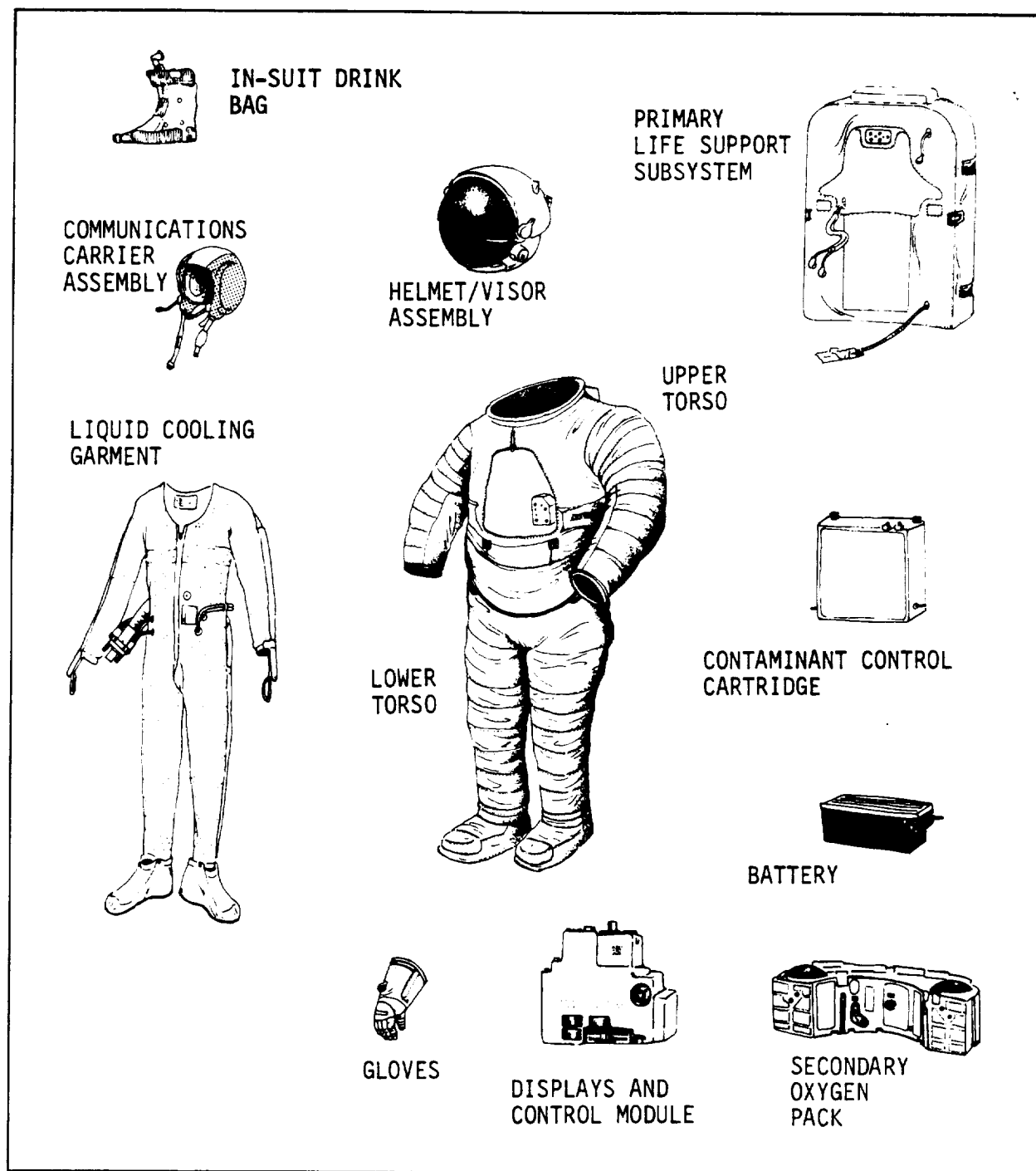


FIGURE 1.2-2.— EMU components.

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Several items of ancillary equipment complement the pressure-suited crewmember's capabilities.

1. Tethers — Two 0.6-meter (24 inch) waist tethers and two 36-centimeter (14 inch) wrist tethers on each EMU (fig. I.2-3) provide safety tethering of the crewmember and EVA equipment. Tether hooks are designed to facilitate pressurized-glove operation and to preclude inadvertent release.



FIGURE I.2-3.— EMU tethers.

2. Mini work station (MWS) — This mechanical device (fig. I.2-4) mounts on the front of the EMU and provides temporary stowage of EVA tools; it has a work tether for additional crew restraint at a worksite. Individual tools are tethered to interchangeable caddies by 0.9-meter (3 foot) self-retracting tethers.



FIGURE I.2-4.— The mini work station.

3. Helmet-mounted lights — A self-contained, crew-adjustable light system that can provide a minimum of 108 lux (10 ft-c) at 0.6 meter (2 feet) is mounted on the helmet for working illumination (fig. 1.2-5).

4. Helmet-mounted television — The EMU-TV assembly (fig. 1.2-5) can furnish real-time scenes through an S-band radiofrequency link to the vehicle's closed-circuit television (CCTV) system for problem assessment and procedure verification, with onboard recording and relay to the ground possible.

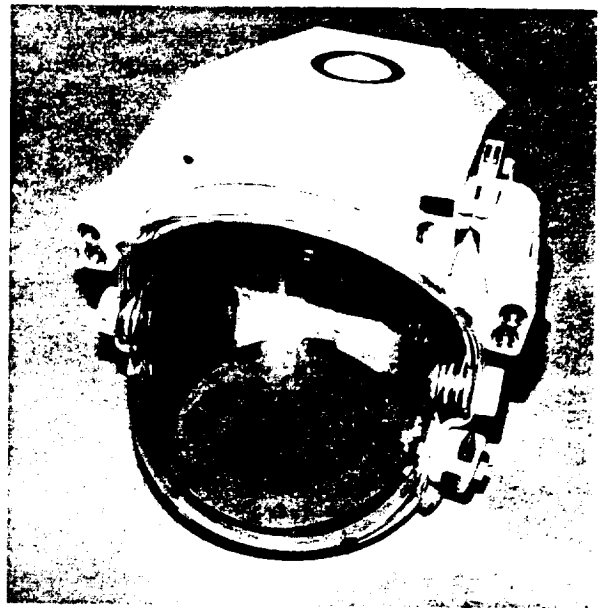


FIGURE 1.2-5.— EMU lights and television.

5. Cuff checklist — The cuff checklist (fig. 1.2-6) provides onsite procedures and reference data and is easily customized by adding payload-specific pages.

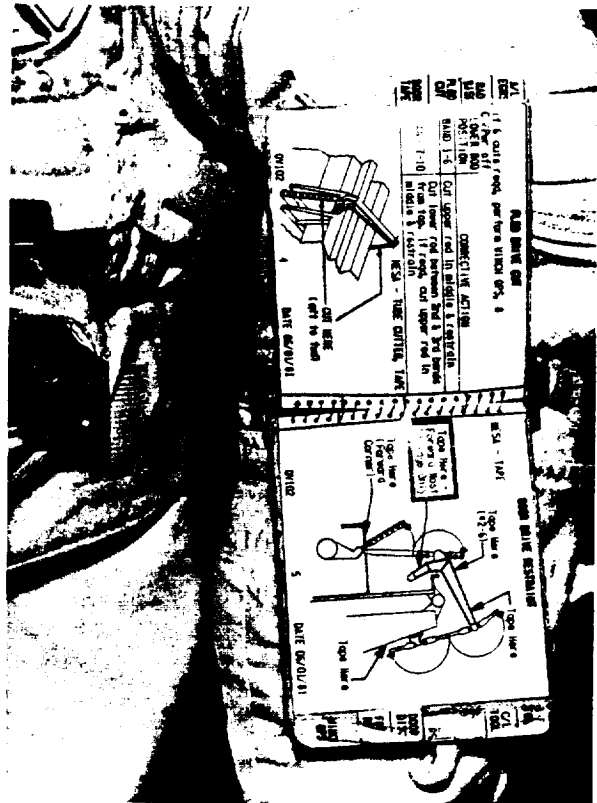


FIGURE 1.2-6.— Cuff checklist.

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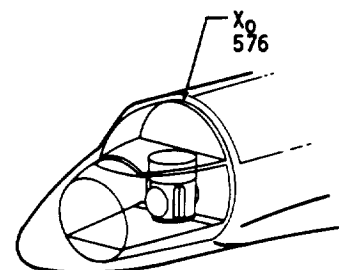
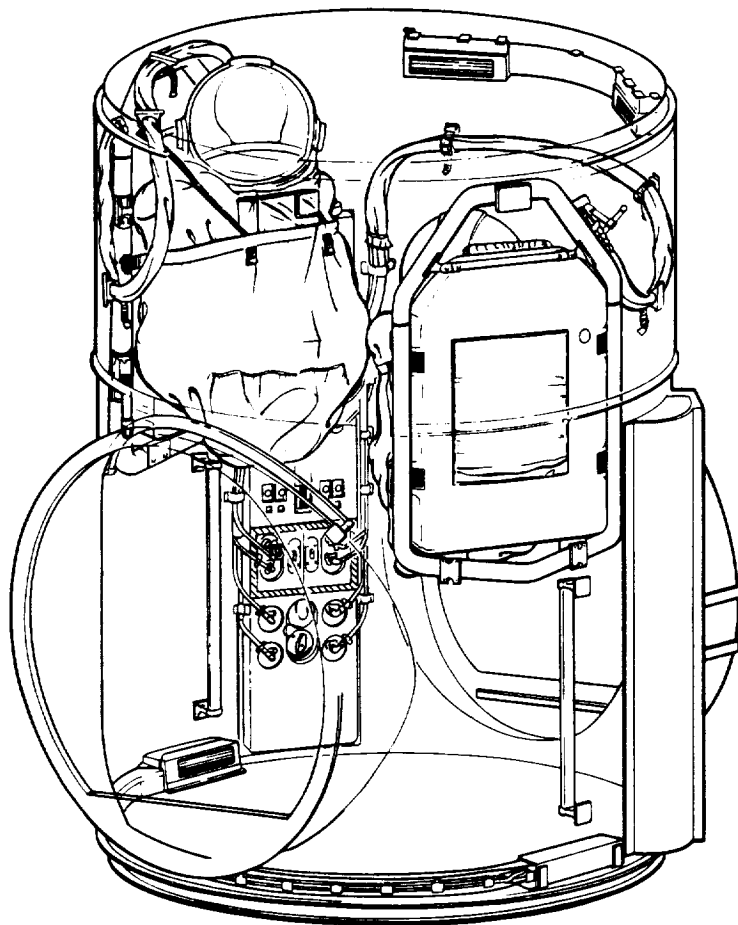


### 3.0 ORBITER EVA PROVISIONS

#### 3.1 Airlock

The Orbiter's airlock provides the means for the suited crewmember to transfer from the vehicle to space without having to depressurize the entire crew compartment. Additionally, the airlock pro-

vides launch and entry stowage of two EMU's and has the interfaces and associated displays and controls for the Orbiter systems that support EMU operations and servicing (fig. I.3-1). The airlock is basically a cylinder 160 centimeters (63 inches) in diameter and 211 centimeters (83 inches) long with two 1-meter (3.3 foot) diameter D-shaped openings with pressure-sealing hatches. The airlock baseline location is in the crew module.



Airlock position  
in crew module

FIGURE I.3-1.— Orbiter airlock.

#### 3.2 Cargo Bay

To provide crewman translation routes about the cargo bay, handrails are installed on both the fore and aft bulkheads ( $X_o$  576 and  $X_o$  1307) and along both cargo bay door hingelines (fig. I.3-2). The handrail configurations illustrated are designed to withstand a maximum crew-induced design load of

900 newtons (200 pounds) in any direction; the tether attachment points are designed for a load of 2550 newtons (574 pounds). Retractable tethers and tether management slidewires will be provided on each side of the cargo bay to support operational safety requirements without interference with the payload ground handling or on-orbit operational envelopes.

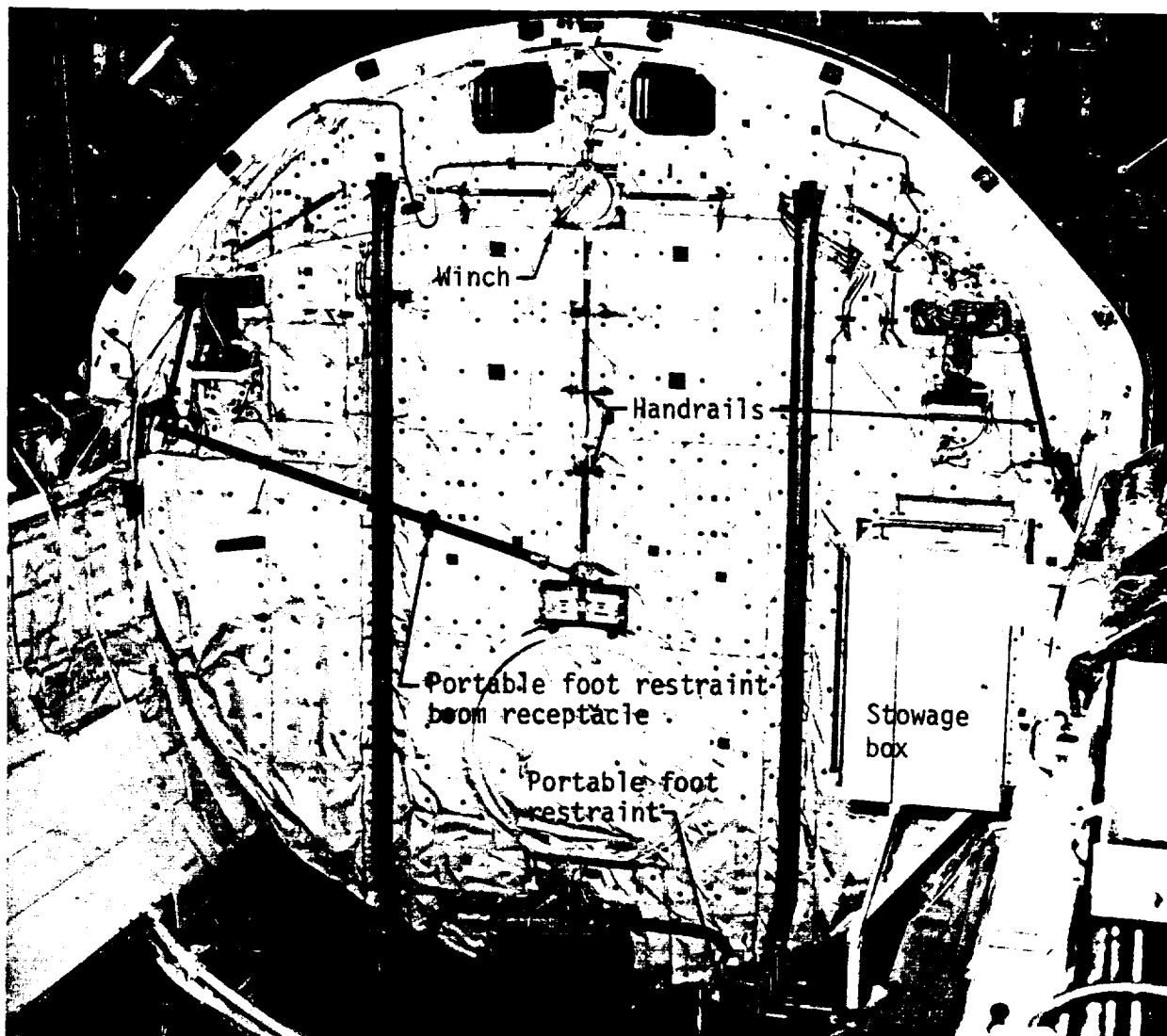


FIGURE I.3-2.— Cargo bay EVA provisions.

The seven cargo bay floodlights aid crew visibility during door operations, payload operations, and EVA's. The metal halide-type lamps provide a minimum 54-lux (5 ft-c) illumination at the cargo bay centerline; the forward bulkhead light provides the same level at 9.1 meters (30 feet). There are some restrictions to activity near these lights because of heat generation, and some may be blocked by payloads.

As many as four cargo bay CCTV cameras (fig. I.3-3) can provide a means for the crewmember to perform limited pre-EVA inspections of the task

areas and allow the intravehicular (IV) crewmembers to observe and verify EV task requirements, accuracy of techniques applied, and satisfactory task completion. Pan and tilt, focusing, and aperture control of the cameras are remotely controlled from the crew module or via ground commands.

Applications of remote manipulator system (RMS) capabilities in conjunction with EVA are under study; however, the RMS television camera and the light located near the end effector may be used to enhance EVA capabilities. The RMS end effector also incorporates an EVA handrail.

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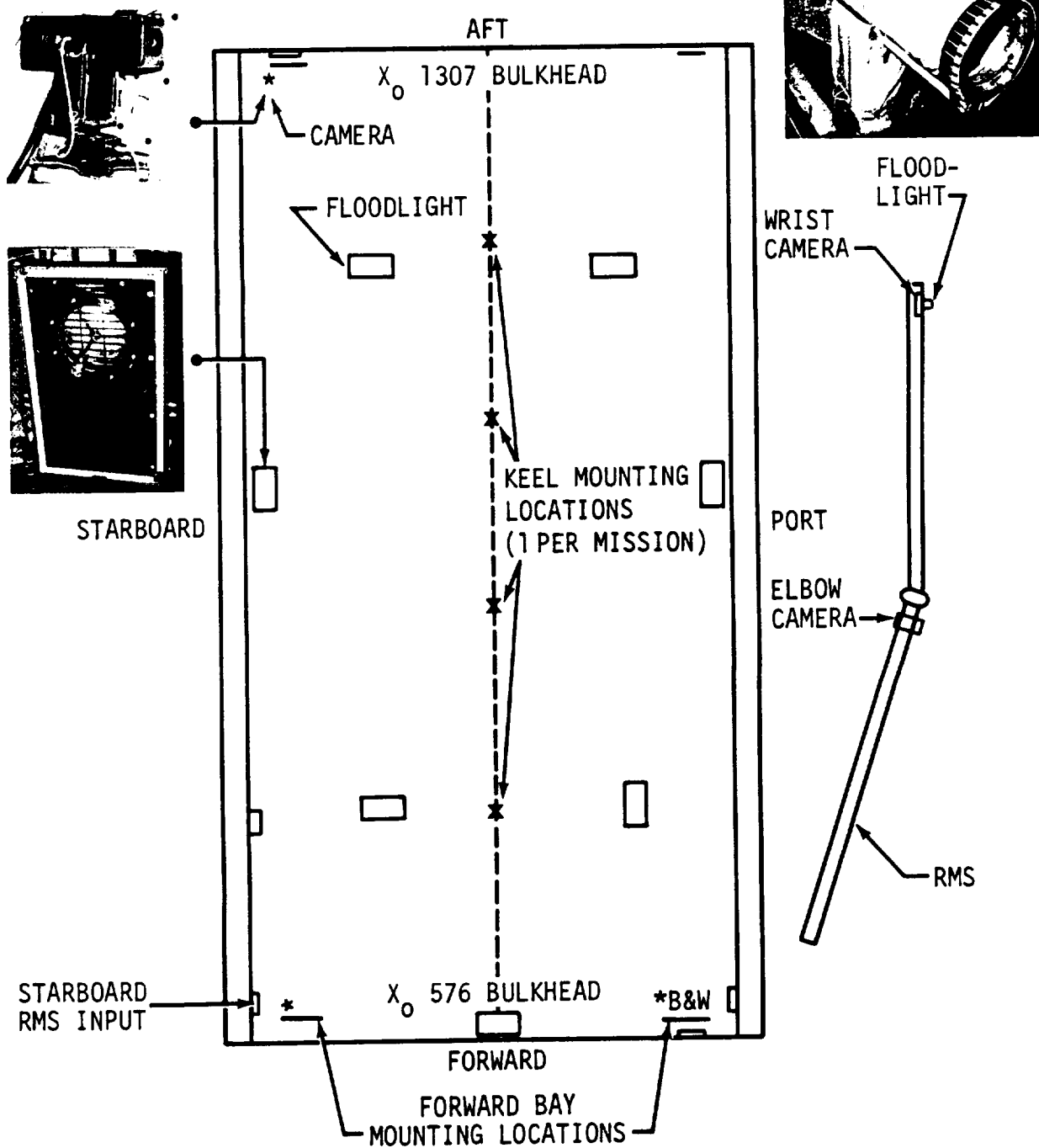


FIGURE I.3-3.— Cargo bay EVA provisions schematic.

A stowage box with integral handrails and foot restraints provides for stowage of EVA tools and support equipment. The box can be installed in any of several locations along the sill longerons in the cargo bay (fig. 1.3-2). Additional stowage space is being provided underneath the liner in the first 1.22 meters (48 inches) of the cargo bay. Space may be provided to stow payload EVA support equipment, the weight and volume of which will be negotiated by the user and the STS.

### 3.3 EVA Voice Communications

Nominal communications between the Orbiter and as many as two EVA crewmen consist of interference-free two-way UHF contact using three frequencies. In its EVA mode of operation, the Orbiter's UHF communications system provides automatic relay to the EVA crewman of the S-band or K<sub>u</sub>-band voice transmissions from the ground stations to the Orbiter. S-band downlink of the EVA crewman's voice to the Orbiter is also accomplished, providing two-way voice communication with the ground. With the deployment of the

Tracking and Data Relay Satellites, ground station coverage via S-band or K<sub>u</sub>-band will be available as much as 90 percent of the time (fig. 1.3-4).

Two-way voice communications among the Orbiter, the EVA crewmembers, and the mission control center can certainly enhance the success of any EVA task. Safety-critical EVA tasks should not, however, be dependent on two-way communications. If the crewman is not autonomously capable of performing the task, communication has become a single-point failure.

The effectiveness of EVA voice communications depends on several factors. The Orbiter's transmission power is 0.25 watt in the EVA mode — the same as that of the EMU. The effective maximum range for EVA communication varies from 70 meters (200 feet) to 9 kilometers (5 nautical miles) depending on the location of the EMU with respect to the vehicle and on possible blockage from payload structures. The lesser range occurs in the region above the cargo bay, and the greater occurs to the sides of the Orbiter.

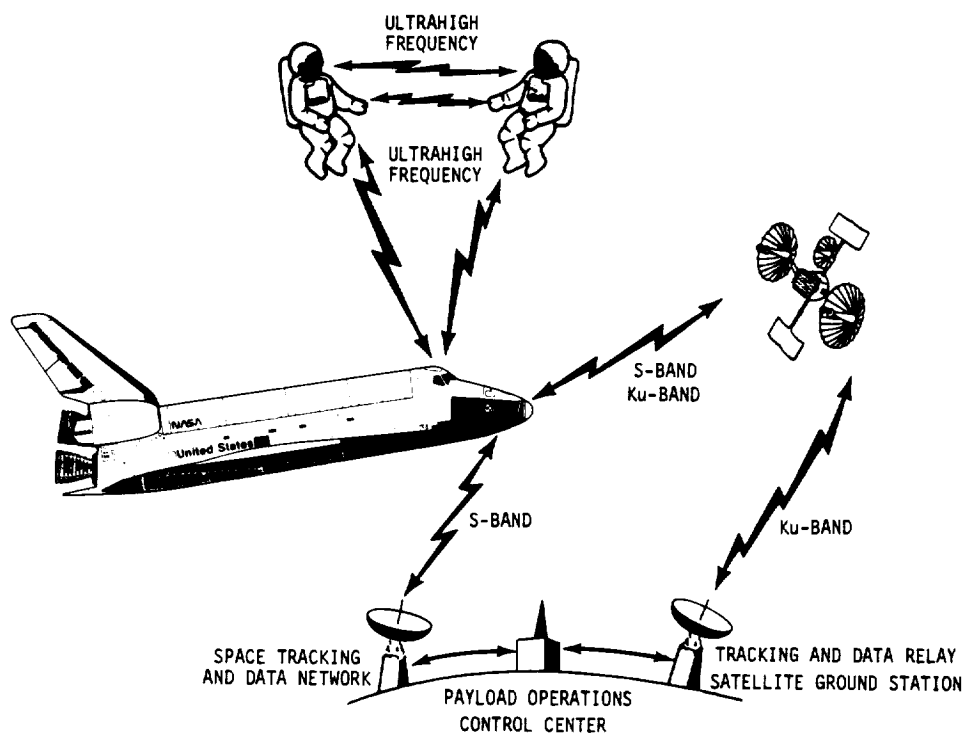


FIGURE 1.3-4.— EVA communications.

#### **4.0 EVA EQUIPMENT**

Various types of EVA equipment have been developed by the STS to provide a wide range of EVA capabilities. Although most items of equipment were developed to satisfy specific needs, the full range of applications has yet to be determined.

Appendix A contains a list of equipment available for support of EVA. Inclusion in the manifest of

those items not otherwise baselined for a particular mission may be requested by the user in the Payload Integration Plan (PIP) and would then be weight chargeable to the payload. In the interest of standardization and simplified crew training, users shall consider use of the existing tool inventory to satisfy their requirements.

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#### 4.1 Manned Maneuvering Unit

The MMU (fig. I.4-1) is a self-contained propulsive backpack designed to increase the Orbiter crew's EVA mobility by extending the range of their activities from the cargo bay to other portions of the spacecraft, to appendages of payloads protruding from the cargo bay, or to other spacecraft entirely. It attaches to the EMU and can be donned and doffed by one unassisted crewmember. Gaseous nitrogen is used as the propellant with redundant design to ensure that no single credible failure can disable the unit. The MMU is stored in the forward cargo bay on the flight support station (FSS) designed specifically for that purpose (fig. I.4-2).

The MMU has complete six-degree-of-freedom control authority with spacecraft-type piloting logic, enabling it to perform a full range of translation or rotation maneuvers either singly (i.e., one at a time) or in combination. Control inputs are through two hand controllers; the left-hand controller handles three-degree-of-freedom translation inputs and the right-hand controller handles three-degree-of-freedom rotational inputs. The maximum range of the MMU is approximately 914 meters (3000 feet). On early flights, however, its range will be limited to approximately 91 meters (300 feet).

The MMU also has the capability to perform automatic attitude hold on command. This capability is typically sufficient to damp out the effects of the user's limb motion; however, it is usually not adequate for tool use loads or similar activity.

The MMU has a total impulse of 6192 N-s (1392 lb-s), yielding a differential velocity capability of 21 m/s (70 ft/s) when a total mass of 335 kilograms (737 pounds) is assumed. The MMU propellant may be reserviced in the FSS during an EVA in less than 20 minutes.

Electrical power is provided by two batteries capable of supplying 2.7 megajoules (752 W-hr) of energy, sufficient for one nominal 6-hour EVA.

#### 4.2 Portable Foot Restraint

A portable foot restraint (PFR) (fig. I.4-3) was originally designed to provide restraint to the EVA

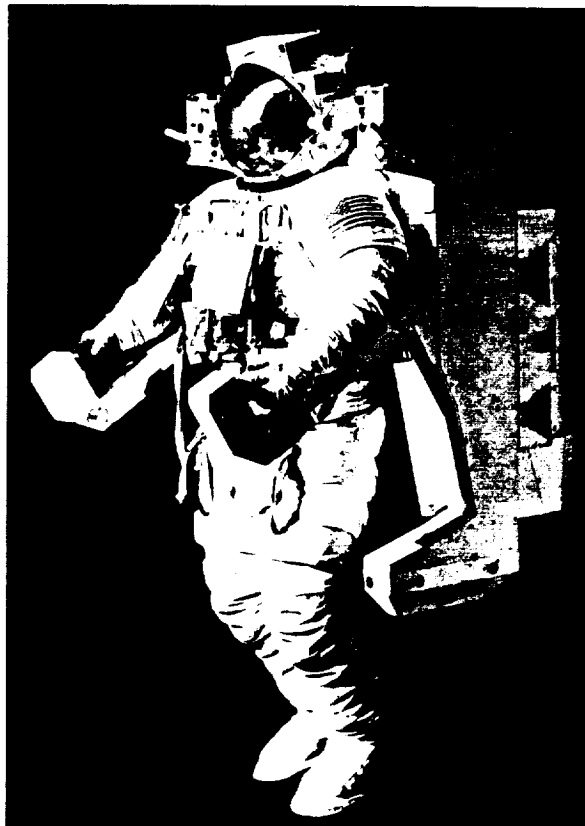


FIGURE I.4-1.— Manned maneuvering unit.

crewmember accomplishing cargo bay mechanical system contingency tasks. It consists of a foot restraint platform with pitch and roll adjustment capabilities, an extension arm, two telescoping booms, and a centerline clamp. A telescoping boom is mounted on the bulkhead handrails at each end of the cargo bay for launch, and the centerline clamp is stowed in the cargo bay stowage box. The platform extension arm is locked into either the centerline clamp or a fitting on either of the telescoping booms to provide restraint for work on the centerline door latches or the bulkhead door latches, respectively. A female fitting to accept the extension arm can be incorporated into the payload design as required to provide payload worksite restraint.

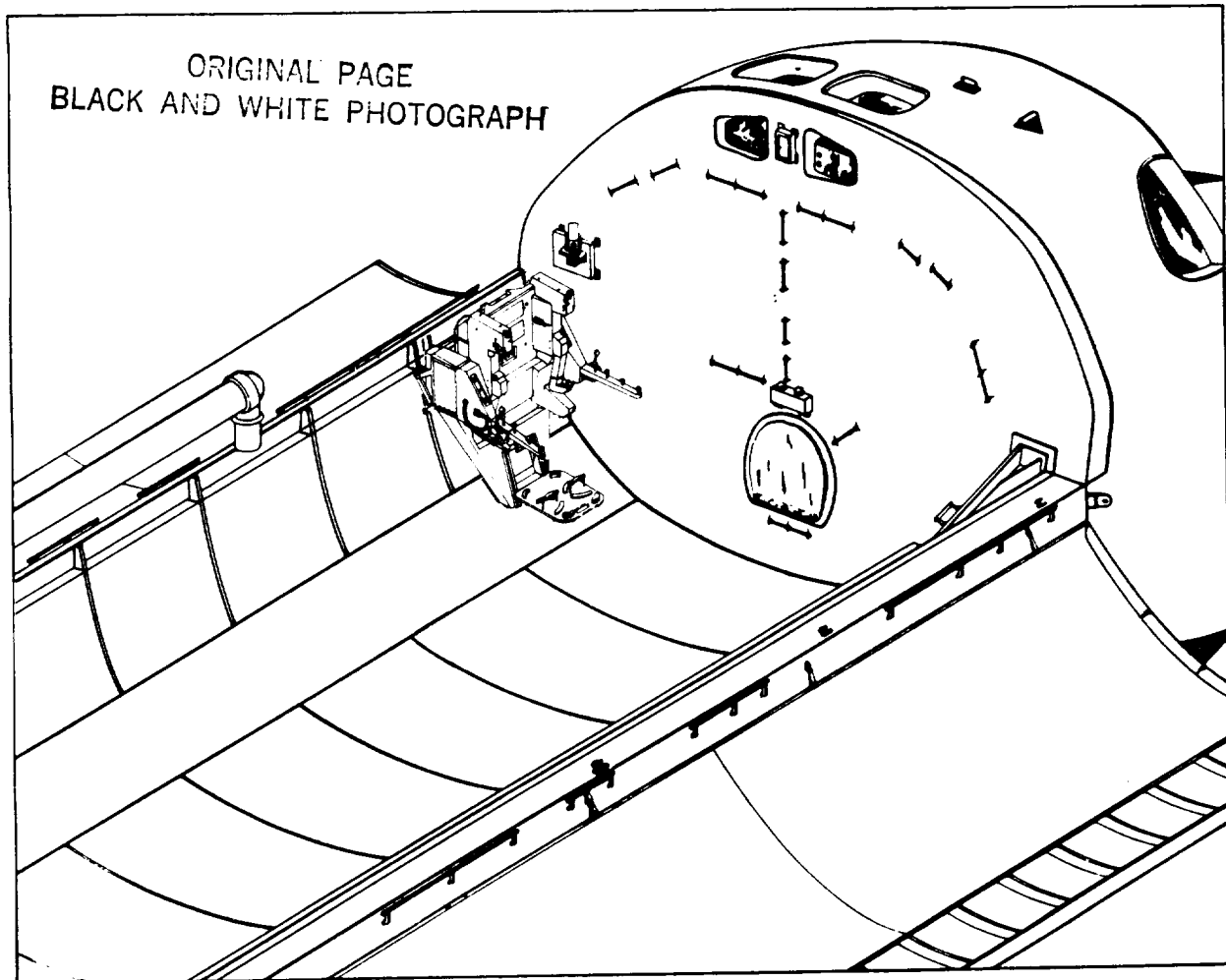


FIGURE I.4-2.— MMU launch stowage.

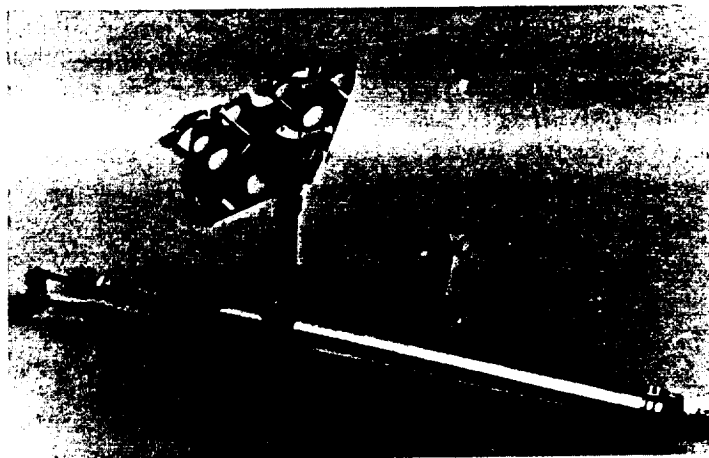


FIGURE I.4-3.— Portable foot restraint.

### 4.3 Manipulator Foot Restraint

The manipulator foot restraint (MFR) (fig. I.4-4) provides restrained access to EVA worksites within the reach of the RMS. Rigidizing provisions with the worksite are not provided, however, and the upper limit to loads induced by the crewman has yet to be determined. As a portable work station, the MFR provides for tool stowage and transfer of large modules from stowage sites to worksites.

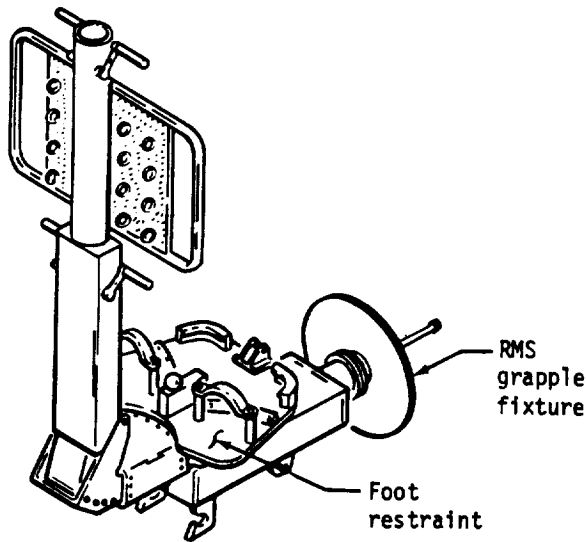


FIGURE I.4-4.— Manipulator foot restraint.

### 4.4 EVA Tools

Many EVA tasks on previous space missions have been accomplished using off-the-shelf industrial or consumer tools with modifications to enhance handling/gripping or to add tether provisions to prevent loss. Previous orbital EVA missions have in-

dicated that, when properly restrained, the crewman can perform many of the manipulative operations on orbit (using modified standard tools) that can be performed in an Earth environment. Therefore, given adequate interface designs (i.e., designing payloads for EVA servicing), a moderate complement of handtools may satisfy Shuttle payload servicing requirements. The high tempo of operations of the STS will require, however, that future EVA tasks be made compatible with existing EVA capabilities rather than depending on the crewmember to make the task work. For this reason, the design of EVA tools should closely follow the design criteria in Part II.

The Orbiter baseline configuration will include only those EVA tools required to satisfy vehicle requirements (fig. I.4-5). Where payload requirements cannot be satisfied by baselined tools, the additional tools required will be chargeable to the payload.

The tools currently baselined for early STS flights were selected for jam removal and for bypassing or disconnecting cargo bay mechanical systems. Most are modifications to standard tools and are stowed in the cargo bay stowage box.

There are two manually operated winches in the cargo bay, one mounted on each bulkhead (fig. I.4-6). The winches were developed to assist in closing the payload bay doors in the event of door drive failure or disconnect. The winch line is a 7.3-meter (24 foot) Kevlar rope with a hook attached to the free end. The load is transmitted to the reel and rope by the winch ratchet handle through a gear system. This load is limited to 1935 newtons (435 pounds) by a torque limiter incorporated in the winch handle. The rope can also be ratcheted out under this load. Additional applications of the EVA winch are under study.



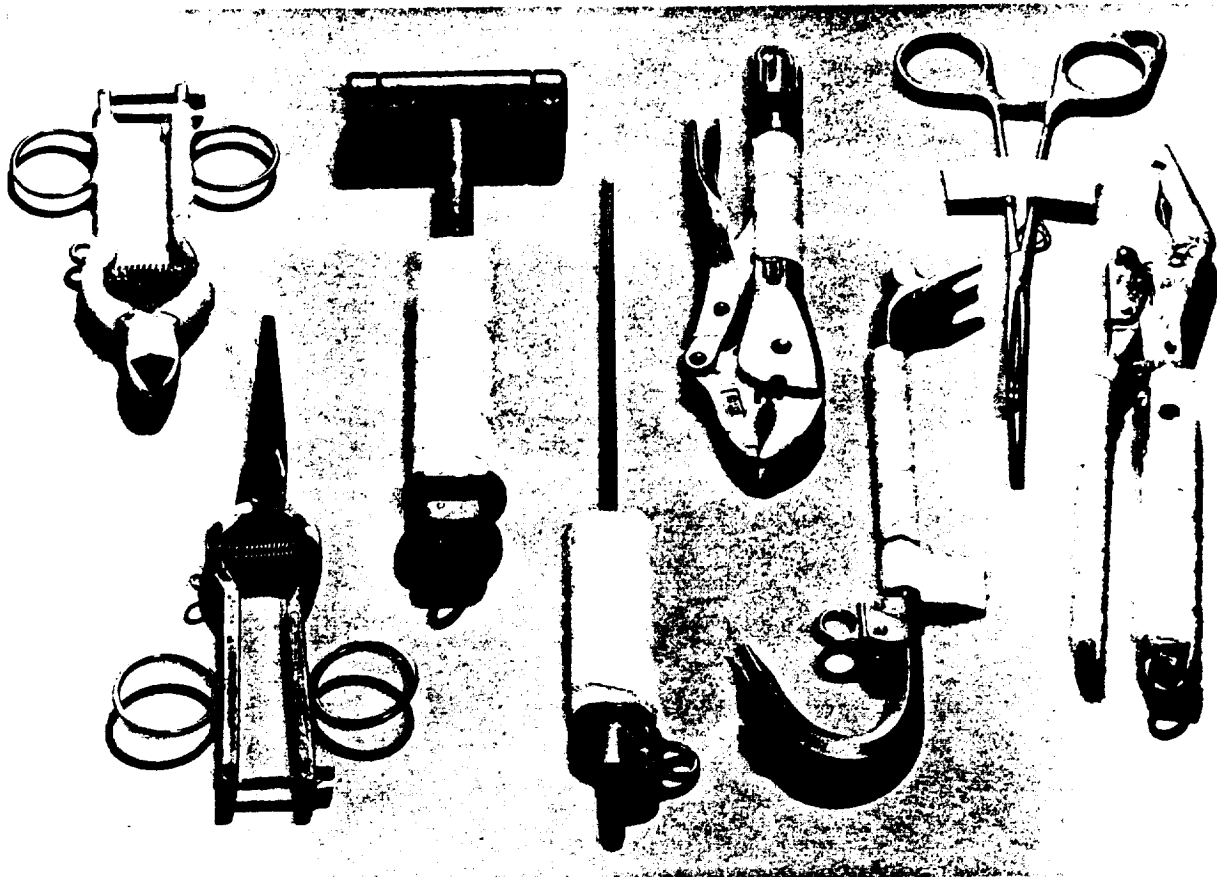


FIGURE I.4-5.— EVA jam removal tools.



FIGURE I.4-6.— Aft bulkhead EVA winch.



## 5.0 FACTORS AFFECTING EMPLOYMENT OF EVA

Each stage in the development of EVA capabilities through the Gemini, Apollo, and Skylab Programs was marked by improved system design, incorporating technological advancements and lessons learned from the preceding effort. Current capabilities and constraints are a summation of these experiences and a continuing advancement in the design of supporting hardware, applied to the EVA requirements identified for STS. All the information presented in this section should be utilized in EVA planning.

### 5.1 Environmental Factors

**5.1.1 Weightlessness** — Crewman capabilities in the zero-g orbital EV environment, relative to Earth-based shirt-sleeve performance, are generally improved for certain manned functions and degraded for others. The major factors that may degrade EVA performance are EMU encumbrances, insufficient working volume, and inadequate crewman restraints. The zero-g environment allows the crewman additional latitude during worksite operations, translation, and cargo transfer. Torso and limb movements are partly a function of the crewman's agility (fig. I.5-1). Translation is practically effortless where mobility aids are availa-

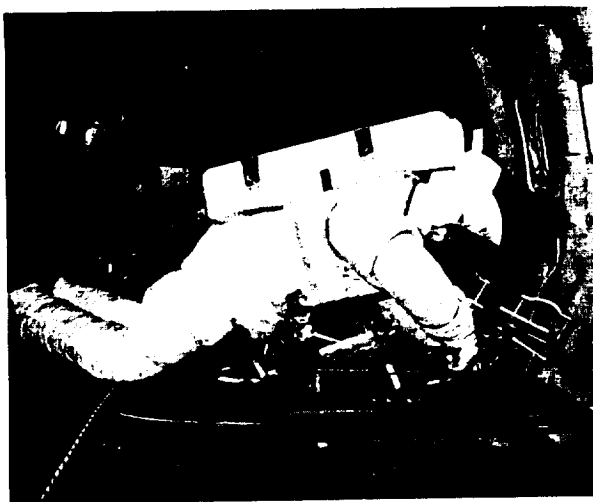


FIGURE I.5-1.— EVA training in zero-g aircraft.

ble, and cargo transfer is affected primarily by package mass/size and time constraints.

**5.1.2 Thermal environment** — The temperature in Earth orbit can range from 116 to 394 K ( $-250^{\circ}$  to  $+250^{\circ}$  F), which is generally within the limits of the EMU. However, because of the configuration of the doors, radiators, and payload bay liners, thermal flux with the Sun shining in the bay can reach levels exceeding the capability of the EMU for an EVA greater than 4.5 hours. In some cargo bay locations where Sun focusing can occur, flux levels may exceed the limits of the EMU, putting the safety of the crewman in jeopardy. The vehicle's orientation with respect to the Sun must therefore be carefully managed during some EVA missions.

**5.1.3 Day/night operations** — With proper consideration given to vehicle/Sun angles, there are no constraints imposed on EVA by day and night cycles.

**5.1.4 Pressure** — In the near-perfect vacuum of Earth orbit, the pressure garment must maintain a minimum pressure of  $21.4 \text{ kN/m}^2$  (3.1 psid) to protect the EVA crewmember from hypoxia. The Shuttle EMU operates at  $29.6 \text{ kN/m}^2$  (4.3 psid), and the Orbiter cabin is normally maintained at  $101.4 \text{ kN/m}^2$  (14.7 psi). Before depressurizing the airlock, therefore, the crewman must denitrogenate to avoid the bends, which would occur at the relatively low operating pressure of the suit (fig. I.5-2). Currently under development is a higher pressure suit, which would relieve the crewmen of their denitrogenation requirements. Availability of this suit, which would operate at  $55.2 \text{ kN/m}^2$  (8.0 psid), is not expected before 1985.

### 5.2 Consumables Servicing

The limit of three two-man, 6-hour EVA's is in part based on Orbiter consumables budgeted for EMU servicing. The same factors limit airlock repressurizations to three. Planning additional EVA's would require "kits" of the consumables necessary to support them. These consumables kits would be chargeable to the payload.

The planned MMU requirements may also impose demands for gaseous nitrogen exceeding that available in the baseline configuration. The mass of

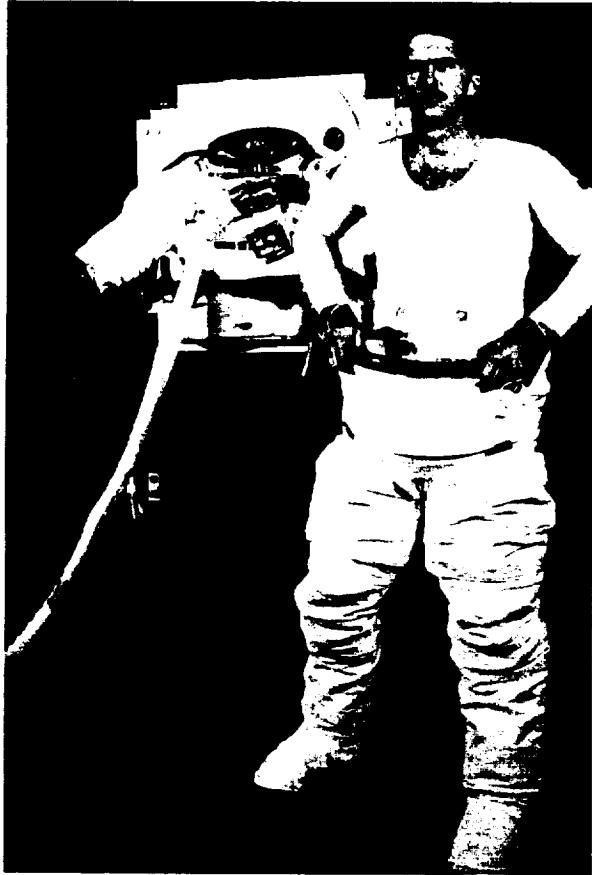


FIGURE I.5-2.— EMU donning.

nitrogen deliverable to the MMU is a function of the supply pressure, which is, in turn, a function of the quantity remaining in the Orbiter's tanks. Budgeting the total nitrogen demands over the full mission time line may require that additional quantities be launched to support that mission.

### 5.3 Space Suit Factors

**5.3.1 Mobility, reach, and force application** — The EMU pressure-garment assembly (PGA) components are designed to provide bending and centers of rotation of the mobility joints to closely approximate the natural body joint movements (fig. I.5-3). The PGA mobility joint system includes the shoulder, waist, hip, knee, ankle, elbow, wrist, and hand systems, which allow the crewman freedom of movement in both the pressurized and unpressurized modes. The total EMU system

design permits the crewman to maintain a natural body position without excessive force and to perform complex mobility functions. The pressurized, integrated EMU minimum design requirements for mobility range are given in figure I.5-3.

By design, pressurized anthropomorphic garments require a force by the crewman to overcome friction inherent in mobility joints. The PGA joints are designed to maintain neutral stability throughout the full range of motion when pressurized to 29.6 kN/m<sup>2</sup> (4.3 psid). The Shuttle EMU suit-joint neutral stability feature alleviates the requirement to apply a counteracting force to maintain a desired position, and the total force required to change position is less than that required in the Apollo A7L suits.

Although the torques associated with space suit motion are relatively small, certain repetitive tasks requiring arm, wrist, or hand movements tend to fatigue the EV crew. Tasks such as the manual removal or replacement of threaded fasteners, long-duration tasks requiring continuous force-torque application, and extended gripping functions should be avoided in payloads designed for EVA servicing. If such equipment designs are mandatory, tools to assist the EVA crewman may be required.

In evaluating the reach capability in the Shuttle EMU, two aspects should be considered: (1) the straight-ahead reach of the suited crewmember, which is limited by the nearest interference point to the palm of the hand, and (2) the reach in all directions of a suited crewmember in a properly restrained position. In the first case, the reach is a function of the anthropometry of the subject. The overall reach envelope of a suited subject, in addition to being dependent on his anthropomorphic percentile, varies according to the nature of the restraint and the requirement for one- or two-handed operation at the reach limit. Representative depictions of the Apollo and Skylab reach envelopes are shown in figure I.5-4. Although testing is not complete, Shuttle EMU reach envelopes are generally comparable. The optimum area for one- or two-handed operation is centered about the upper chest and lower face area of the crewmember — a factor to be considered in the positioning of foot restraints, for instance, if the crewmember is required to perform a manipulative task.

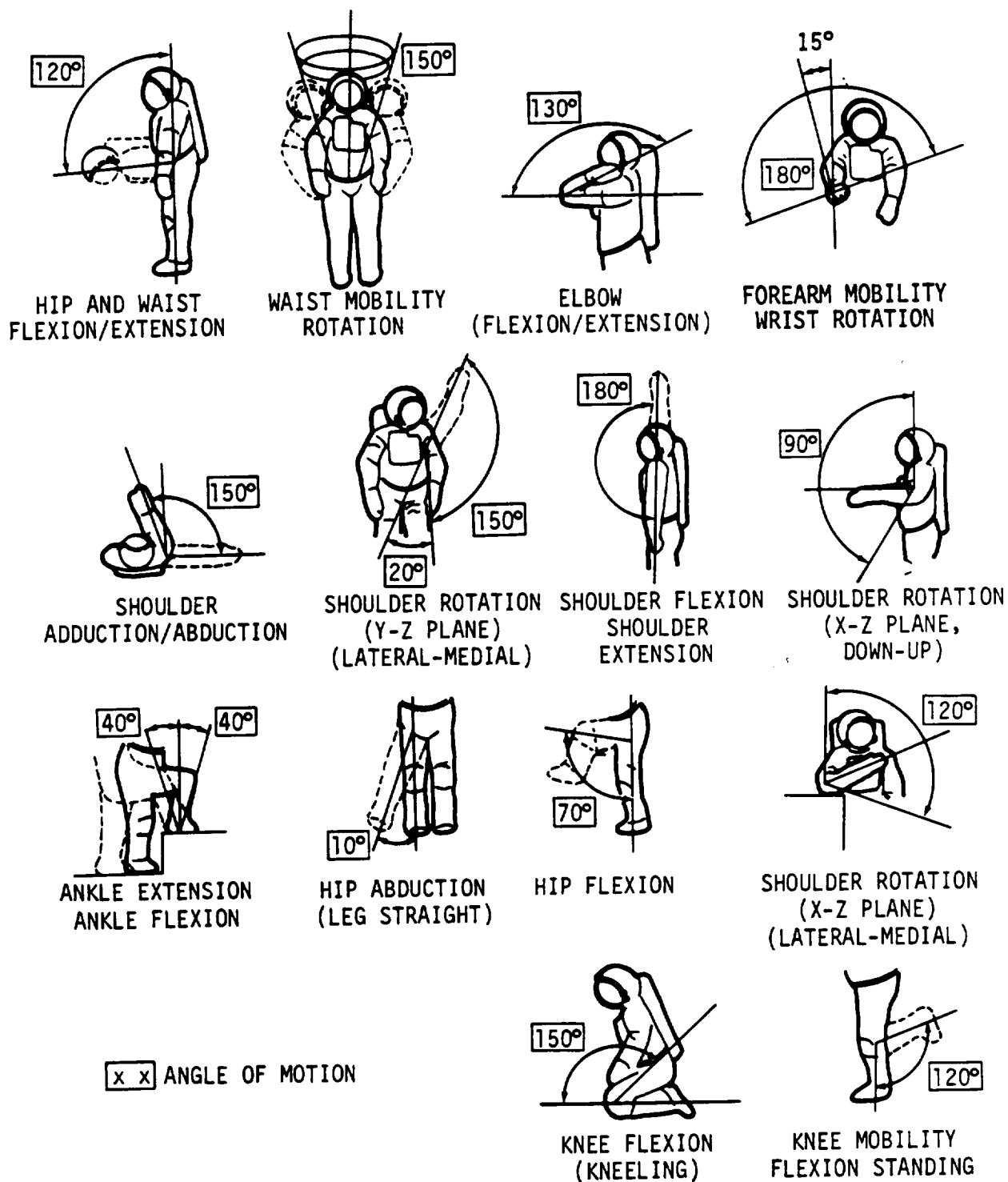


FIGURE 1.5-3.— EMU mobility.

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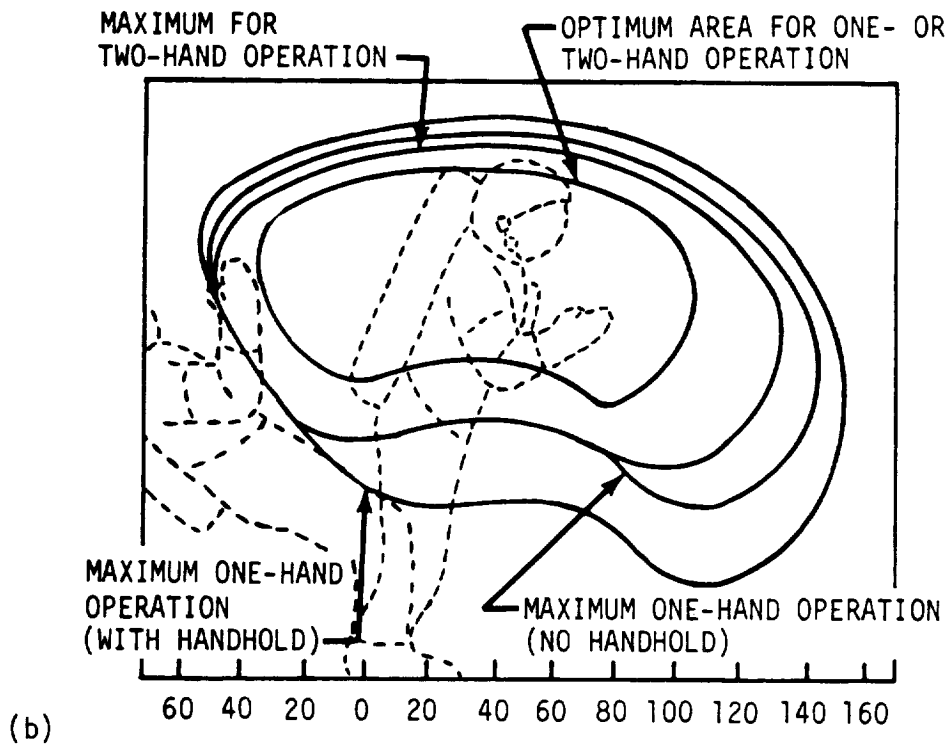
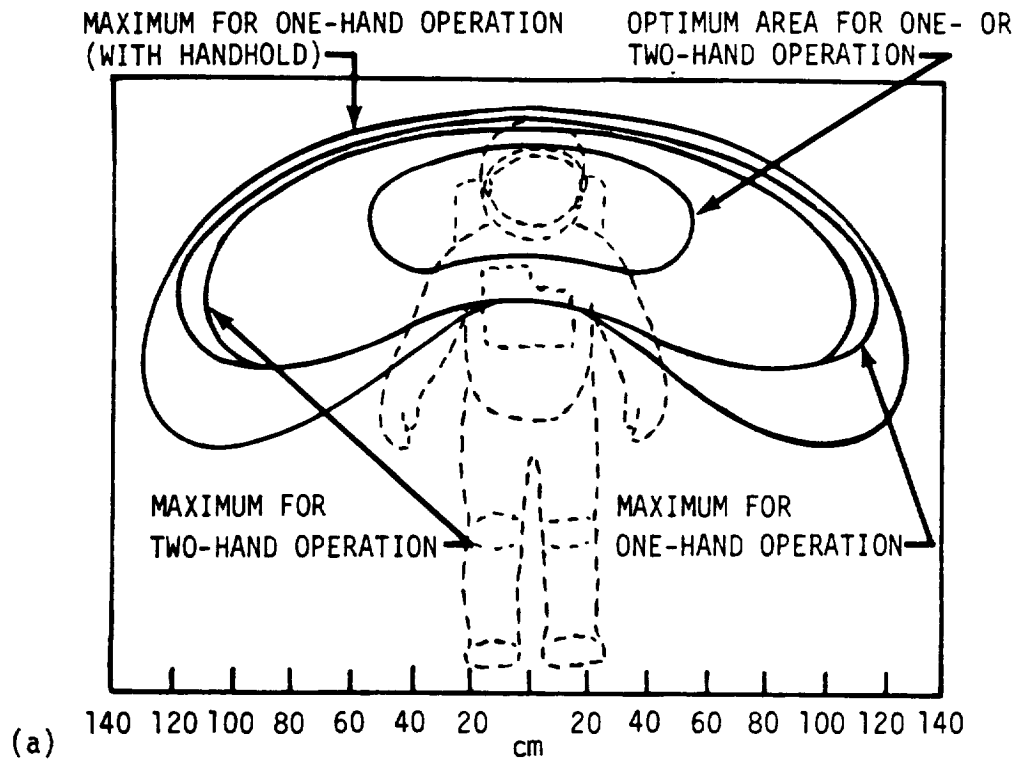


FIGURE I.5-4.— EMU crewman reach envelope. (a) Side reach. (b) Fore-aft reach.

Like reach capability, force application must be considered both with and without restraints. Analyses have shown that the maximum force capability without restraints is a function of the subject's mass and the distance (arm reach) at which the force is applied. The maximum distance a force can be applied by a free-floating crewman is approximately 0.6 meter (2 feet) since the crewman's arm will no longer be in contact with the work structure after his mass center has moved this distance. Using a subject mass of 73 kilograms (160 pounds), it was determined that the unrestrained crewman can apply a force of 4.4 newtons (1 pound) for approximately 4.5 seconds, a 22.2-newton (5 pound) force for 2.1 seconds, and a 44.5-newton (10 pound) force for 1.4 seconds before his mass center moves outside the 0.6-meter (2 foot) envelope. In general, force application limits are higher when the arms and hands are being drawn together than when the arms are pushing apart. Low-force, short-time operations such as actuation of toggle and rotary switches, surveillance of controls and displays, visual inspections, etc., can be performed by an unrestrained crewman in a weightless environment.

To compare the results obtained when a crewman was properly restrained, water immersion facility testing was conducted and demonstrated the following.

1. The suited subject, in foot restraints only, was able to apply a straight-ahead push force of 200 newtons (45 pounds) for 3 seconds, 89 newtons (20 pounds) for approximately 15 seconds, and 44 to 67 newtons (10 to 15 pounds) almost indefinitely.
2. When a waist tether was attached, a 133-newton (30 pound) force was exerted with no difficulty and a 200-newton (45 pound) force could be maintained for 1 minute.

These forces were reduced approximately 30 percent when the point of force application was moved near the top of the subject's reach envelope. Although these data cannot be used to determine detailed specifications, standards, or design requirements, they do indicate the necessity of providing adequate restraint and proper biomechanical body orientation to the EVA task to optimize the crewmember's force output. In this regard, foot restraints have proved to be the most effective

means of stabilizing the crewman and maximizing his capabilities.

EV gloves degrade tactile proficiency relative to bare-hand operations (fig. I.5-5). Dexterity can be compared to that of heavy work gloves, but many standard-type handles, knobs, toggle switches, and buttons can effectively be operated with EV gloves. Considerable attention should be given to the design of manual interfaces to preclude the early onset of fatigue. The design specifications for glove interfaces are given in Part II of this document. Where tasks are sensitive to limits on dexterity, interface compatibility can be verified in glove box evaluations.

*5.3.2 Mass handling* — The capability to maneuver equipment modules, experiments, payloads, and rescue systems in the zero-g environment, independent of assisting mechanisms, will enhance on-orbit EVA payload servicing. Appropriate crew mobility aids and restraints and the design of the cargo requiring transfer are the key elements in EV equipment handling. The designer of EV transportable hardware must consider module size, quantity, geometry, mass transfer distance, time, temporary stowage, number of EVA crewmen, and handhold/grasp location relative to the mass center of gravity.

Actual zero-g experience in mass handling is limited to the Apollo trans-Earth EVA's, in which handheld packages of 0.6 meter (2 feet) diameter

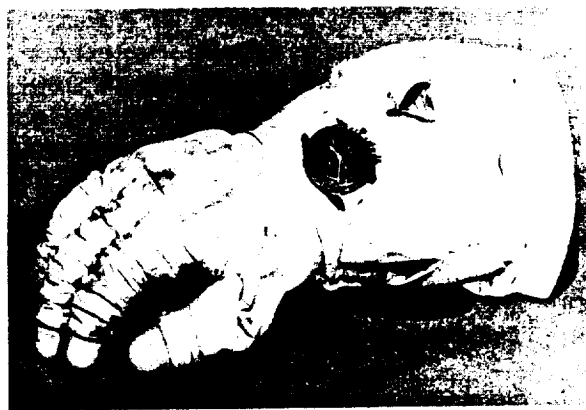


FIGURE I.5-5.— EMU glove.

and 38.6 kilograms (85 pounds) were easily transported by the crewman. These EVA's did not begin to approach the EVA crewman's maximum capabilities, however, and further studies have been made.

Space-suited simulations conducted on the KC-135 zero-g aircraft with packages of 102 by 76 centimeters (40 by 30 inches) frontal dimensions and a mass of 82 kilograms (180 pounds) did not disclose translational, positioning, or control problems other than those associated with aircraft perturbations. Packages with a moment of inertia in excess of  $4.04 \text{ kg-m}^2$  ( $350 \text{ in-lb-s}^2$ ) became increasingly more difficult to control and position.

**5.3.3 Translation rates** — The distance translated and the frequency of translation were not major factors relative to crew EVA time lines in previous orbital space programs. However, the 18.3-meter (60 foot) Shuttle Orbiter payload bay requires more accurate planning of EVA crew time. The forces required to handle cargo in a gravity-free environment are those induced by the inertial properties of the cargo and the crewman. There are no theoretical limits on the mass of cargo that can be transported: limits are imposed only within the constraints of transport time, safety (crew and vehicle), control requirements, acceleration limits, vehicle geometry, positioning accuracy, etc. Crew translation velocity in the vicinity of equipment potentially hazardous to the crewman, his support equipment, or the vehicle/payloads must be reduced to satisfy both mission and safety requirements.

A nominal translation rate of 0.16 to 0.33 m/s (0.5 to 1.0 ft/s) has been determined for the unencumbered Shuttle crewman. Space-suited water-immersion cargo-transfer simulations have reported crewman velocities ranging from 0.09 m/s (0.3 ft/s) for 748 kilograms (1650 pounds) mass transfer to 0.21 m/s (0.7 ft/s) for transporting the smaller ( $<0.03$  cubic meter ( $<1.0$  cubic foot)) modules. For time-line estimations, 0.16 m/s (0.5 ft/s) is used.

## 5.4 Task Design

**5.4.1 Introduction** — When considering the design of an EVA task, the user must take the previously described factors as given constraints and the

specifications in Part II of this document as minimum requirements. Very wide latitude still remains in the development of the end-to-end EVA task for the user to optimize his design to enhance mission-success probability and minimize development efforts and crew training requirements.

**5.4.2 STS EVA design philosophy** — In developing an approach to EVA design, the factors of task criticality and complexity should first be understood.

**5.4.2.1 Criticality:** The STS identifies three levels of criticality: mission enhancement, mission success, and safety critical.

Mission-enhancement EVA's are EVA's that include tasks which result in increased achievement of mission objectives; e.g., cleaning optical surfaces or restoring a partially degraded system to full capability. They are usually tasks that get "piggybacked" onto more important tasks, depending upon their relative mission priority.

Mission-success EVA's are those that are required to achieve mission objectives. For example, planned tasks would include replacement of Space Telescope scientific instruments, removal of payload appendage launch tiedowns, retrieval of film, and performance of EVA experiments. Unscheduled mission-success EVA's would include backup operations to override or bypass failed payload systems that would otherwise be prevented from operating.

At the highest level of criticality are the contingency (safety critical, unscheduled) EVA's which must be accomplished to enable the safe return of the Orbiter. They are performed to repair failures in safety-critical systems. Included in this category would be any EVA task required by a user to satisfy STS fail-safe criteria for his payload.

**5.4.2.2 Complexity:** Three levels of complexity are defined: simple, intermediate, and complex. A simple EVA task is one that requires no special tools, restraints, or mobility aids and does not expose the crew to unique hazards. A task that requires additional tools or equipment but is still procedurally simple would be considered intermediate in complexity. A complex EVA requires a significant extension of capabilities, such as new and complex tools, poses access or restraint problems,



moving large items from place to place, potential hazards, or long duration.

**5.4.2.3 Application:** In evaluating payload design relative to accomplishment of EVA requirements, the STS will interpret the requirements of this document strictly if the EVA is safety critical. Factors such as adequate access to mechanisms, sufficient lighting, good crewman restraints, avoidance of hazards such as sharp edges, design of tools for pressurized-gloved-hand use, and reasonable forces and torques are required. Suitably accurate training hardware will be required, as will a rigorous demonstration of task feasibility.

In the category of mission-success EVA, the level of effort required for design and training will be

proportional to the complexity of the operation. Some requirements will apply regardless of the type of EVA, principally those related to the safety of EVA crewmembers (adequate clearances, no sharp edges, avoidance of electrical hazards, moving mechanisms, etc.). However, simple operations, especially those that can be done one-handed with standard tools and low forces, will usually not require special training articles or mockups. Tasks of intermediate difficulty may require low-fidelity neutral-buoyancy mockups to evaluate access routes and restraints, but the actual mechanisms can be tested and trained for with the use of flight hardware. Complex EVA's typically require special mockups and possibly even iterative design evaluation efforts involving pressure-suited exercises in a neutral-buoyancy facility.



## 6.0 EVA MISSION INTEGRATION

The STS payload integration process shall be utilized to define and document all payload EVA requirements. Determination of these requirements will be accomplished during the development of the Payload Integration Plan (PIP) with the payload organizations. The EVA scenario and interface requirements will be developed and documented in the PIP EVA Annex (Annex 11). For the payload designer, the incorporation of these man-machine interfaces constitutes a unique requirement for user/STS interaction during payload development. The fact that the launch vehicle is both manned and reusable not only adds man's on-orbit abilities to the Shuttle's available services, it also demands consideration of factors that will ensure its safe return. The keys to the successful integration of EVA capability are the consideration of EVA requirements at the earliest stages of payload design and the concurrent establishment of an effective, though informal, design review activity with the STS.

### 6.1 Formal Integration Responsibilities

A payload EVA is an optional service to the user, and its inclusion in the PIP initiates a series of

EVA planning activities, which can generally be categorized as

- Design review
- Procedures development
- Supporting hardware design
- Flight planning
- Crew training
- Flight performance

Within these categories are tasks which are either the joint responsibility of the user and the STS or the sole responsibility of one organization (table I.6-1).

**6.1.1 Design review** — The user has the responsibility to ensure that the payload design meets EVA operational requirements. This means that the guidelines and specifications presented in Part II of this document are followed wherever applicable so that the task has a high probability of success and that the crew is protected from unwarranted hazards. EVA consultation will be provided to the payload by the STS during the payload design and

TABLE I.6-1.— EVA Development Responsibilities

Activity	User	STS
Payload design for EVA task	X <sup>a</sup>	O <sup>b</sup>
Operational evaluation of design	X	X
EVA support hardware design (tools, restraints, etc.) that are payload unique	X	(X) <sup>c</sup>
EVA support hardware operational evaluations	X	X
EVA one-g, WETF, KC-135, altitude chamber, etc., mockups/trainers as required for crew training	X	(X)
Stowage provisions for payload EVA hardware that exceed standard STS stowage provisions	X	(X)
EVA technique development	X	(X)
EVA technique evaluation	X	X
EVA procedures development	X	(X)
EVA procedures evaluation	X	X
FDF procedures development		X
FDF procedures validation		X
EVA crew training		X
Flight performance of EVA tasks		X

<sup>a</sup>X = responsibility.

<sup>b</sup>O = consultation.

<sup>c</sup>(X) = provided by the STS through additional optional service agreement.

development cycle. The Preliminary Design Review (PDR) and the Critical Design Review (CDR) are normally conducted in the same time frame as the Phase I and Phase II Safety Reviews, respectively, with the depth of the review appropriate to the level of the design at that time.

*6.1.2 Procedures development* — The development of EVA procedures to be included in the mission Flight Data File (FDF) consists of several basic steps. Derived from the EVA system design is a set of systems procedures which includes those actions that must be performed to accomplish the EVA task. Well before the system design is complete, however, a series of techniques is developed. These techniques are based on both a general knowledge of EVA capabilities and the current status of the payload design, and they differ from procedures in that they are used to support the payload design. As the design matures to a firm configuration, the techniques are refined and matured into the EVA system procedures for this payload.

The STS is solely responsible for final procedures development into the level of maturity required for incorporation in the FDF. Procedural checklists are formatted into FDF standard books, cue cards, and decals as required. Each element of the flight procedures is validated and when complexity and criticality demand, the use of flight or developmental hardware, high-fidelity training articles, or mission simulators may be required. Procedures verification, the process whereby procedures are tested to determine suitability for flightcrew training, may require use of training-type hardware or a "desk top" evaluation on the flight or a qualification article. For simple tasks, the validation and verification processes are performed concurrently.

*6.1.3 Supporting hardware design* — The development of specialized tools and hardware beyond those included in the list of available equipment is the responsibility of the user. Special tools, translation aids, payload add-on stowage provisions, mission-unique equipment, manipulators, and crew or equipment restraints are some items which might be developed by the STS more effectively. STS-provided, unique EVA hardware to accomplish a payload EVA task must be defined in the PIP.

*6.1.4 Flight planning* — To support STS crew activity planning, a listing of the payload events and

flight conditions that are supported by a planned or contingency EVA is documented in the PIP Flight Planning Annex (Annex 2).

*6.1.5 Crew training* — The conduct of crew training for EVA is the responsibility of the STS. STS EVA training provides a cadre of Orbiter crewmembers qualified to perform EVA tasks (fig. 1.6-1). This training covers the EMU, the MMU, the airlock, and EVA-related Orbiter systems operation and is conducted in classrooms, high-fidelity mockups, and part-task trainers. Instruction in and practice of EVA techniques in simulated weightlessness are provided in the Weightless Environment Training Facility (WETF) using Orbiter neutral-bouyancy trainers with high-fidelity EVA interfaces.

Like the design effort itself, payload training requirements are heavily dependent on the complexity and the criticality of the given EVA task. Training requirements are minimized for simple tasks, tasks that involve use of common techniques and supporting hardware, tasks that have the fewest separate actions or steps required by the crewman, and tasks that are well within the crewman's capabilities and constraints in the pressure-suited, zero-g environment. If the task is safety critical and therefore requires a very high probability for success, if there is small margin for error with regard to avoidance of hazards, or if the sequence of events is time critical with regard to either the task accomplishment or EMU endurance, then training requirements may be significant even if the basic task is simple.

Payload-specific EVA training is performed by the STS using training articles provided by the user with a level of fidelity of direct EVA interfaces appropriate to the complexity and criticality of the task. The STS can develop and procure these training articles for the user as an optional service. Simplicity of the task, commonality of hardware with proven designs, and use of proven EVA techniques contribute significantly to low-cost crew training requirements.

*6.1.6 Flight performance* — It is the STS's responsibility to carry out the mission's EVA requirements. Real-time ground support is also provided as required, and may include expertise from the user organization.

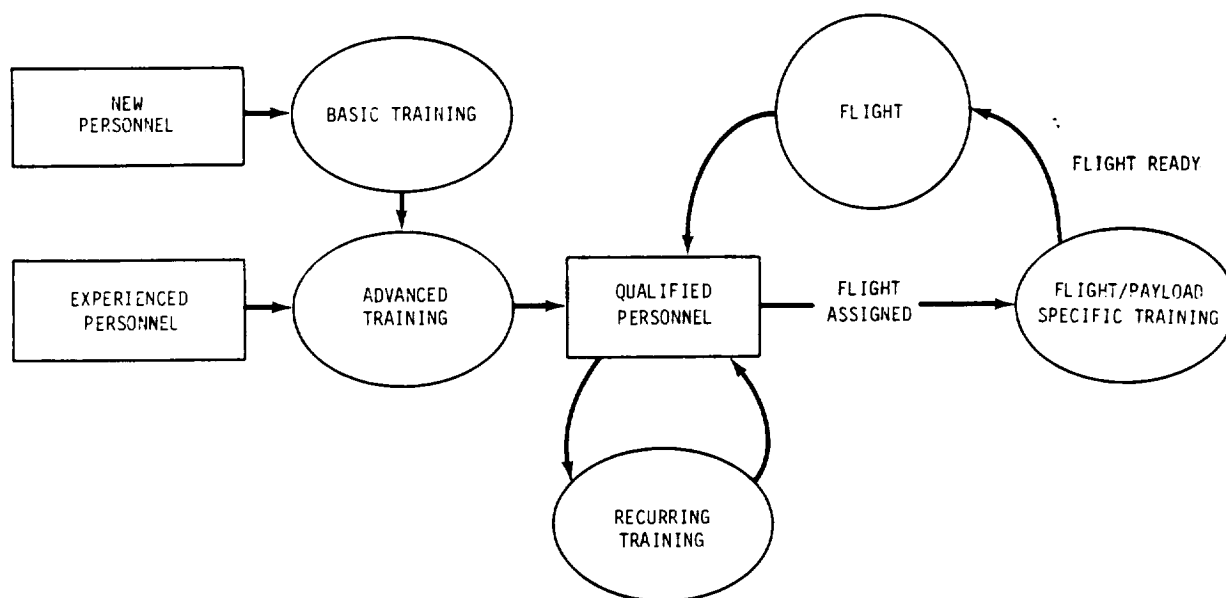


FIGURE I.6-1.— Crew training flow diagram.

## 6.2 Sequence of Activities

The typical sequence of payload integration activities is included in the Shuttle/Payload Standard Integration Plan (JSC-14029). Scheduled EVA requirements are usually identified early in the design concept development from the payload preliminary operational scenario, whereas unscheduled EVA requirements are often identified later as the STS fail-operational/fail-safe criteria are applied to the maturing payload design. In either case, an analysis of the EVA task must then be conducted, beginning with identifying the specific task requirements and then applying the information contained in this document regarding translation, access, restraint, and safety to develop an end-to-end EVA scenario. Some feedback into the design effort will occur at this point, and modifications to the basic payload design may be required.

An early joint user/STS evaluation of the proposed EVA scenario is highly recommended to review safety, verification of EVA hardware interfaces, training requirements, developing procedures, flight planning, and conducting flight operations. Additionally, during this meeting, updates to the Orbiter baseline EVA provisions or changes to the

design criteria based on recent experience may be provided. Every EVA task must be evaluated on its own merits, and this initial informal review activity brings together all the elements necessary to ensure a successful design effort. As a result of the joint review, the user is ready to proceed with the payload design, applying the specific EVA design criteria, and also with preparation of the PIP EVA Annex.

There are three major benefits to be derived by the user from the joint review. First, the user can exercise contacts with the personnel who will be participating in the collective process of integrating his payload with the STS and can benefit from their general EVA experience and lessons learned from other payloads. Additionally, any trade-offs to be considered in selecting different approaches or even choosing to utilize EVA itself can be more clearly quantified. Finally, and as a result of the preceding benefits, the user can proceed with his design efforts with reasonable confidence that all payload and Orbiter requirements are being satisfied and that the chances are minimized for any show-stopping discrepancies to go undetected before the remaining formal reviews are accomplished.

### 6.3 Cost Factors

Throughout this document, references have been made to various payload-chargeable items related to EVA. Costs associated with EVA are described in the STS Reimbursement Guide.

Some factors related to the optional services costs under the general EVA heading are negotiated fees for procedures development, supporting hardware

design, and development and procurement of training articles. In general, any payload-specific weight and volume costs on shared missions increase the charge to that payload. Weight will be increased by any unique payload-supporting hardware such as tools, translation aids, restraint systems, or additional stowage provisions. Payload volume requirements must include payload EVA task worksite volumes.

## 7.0 BASELINED EXTRAVEHICULAR ACTIVITY

This section contains illustrative examples of payload development activities that are baselining EVA tasks. The purpose of the section is to provide examples of actual EVA applications, to demonstrate the application of EVA design criteria and the design and training philosophy espoused in the previous sections, and to cite a sufficient amount of detail to promote the goals of simplicity and commonality of design. It should be noted that the payload configuration descriptions presented here are not controlled information and are subject to change before flight. Should payload changes materially affect the intent of this section, appropriate changes will be made to this section.

### 7.1 Multimission Modular Spacecraft

The Multimission Modular Spacecraft (MMS) is a standardized reusable space platform capable of supporting a wide variety of Earth-orbital programs. The basic structure of the MMS supports modularized power, communications, data handling, and attitude control components which may be combined with other, optional subsystems to support specific payload mission requirements (fig. I.7-1). When launched by the STS, the MMS is secured for launch and positioned for on-orbit deployment by an MMS-unique flight support station (FSS), which can also secure the spacecraft for reentry. In the design of its modularized components, the MMS, in the case of the Solar Maximum Mission (SMM), represents the first payload launched into Earth orbit with an in-flight refurbishment capability.

**7.1.1 Basic EVA task description** — A typical MMS refurbishment mission would consist of Shuttle Orbiter rendezvous with the MMS, capture and berthing of the satellite to the FSS in the cargo bay by means of the remote manipulator system, EVA refurbishment of the MMS as required and, after checkout of the satellite and possible reboost to satisfactory orbit, redeployment of the MMS using the RMS. The FSS, in addition to providing mechanical and systems interfaces between the Orbiter and the MMS, will provide stowage for

replacement modules and restraint provisions and translation aids for the crewmembers. EVA design features of the system include the module retention system (MRS) and the module servicing tool (MST).

**7.1.1.1 Module retention system:** The MRS provides the means of mounting the subsystem modules to the module support structure (MSS). The upper and lower retention mechanisms attach to the MSS by way of two preload mechanism jackscrews. The upper mechanism also mates/demates the module electrical connector(s) as the jackscrews are tightened/loosened (fig. I.7-2). The jackscrews require 7.5 turns with a maximum torque of 95 to 122 N-m (70 to 90 ft-lb) required. Individual modules vary in mass from 122 kilograms (270 pounds) to 227 kilograms (500 pounds).

**7.1.1.2 Module servicing tool:** The MST performs two functions. First, the drive socket interfaces with the retention mechanism jackscrews to provide the necessary torque for mating/demating of the subsystem modules with the support structure. The tool is electrically powered. Additionally, the MST has two latches that serve to lock the tool to the module when driving the jackscrews and renders the MST as a module handling aid which will also mount to the stanchion of the MFR.

**7.1.2 Solar Maximum Mission** — The SMM was launched in early 1980 to conduct various observations of solar activity during the peak periods of the 11-year solar cycle. Several fuse failures have limited the attitude control capability and degraded the scientific return from the mission.

The SMM repair mission (SMRM) being planned would replace the MMS module which contains the failed attitude control components and, in addition, conduct several mission-enhancement tasks on portions of the spacecraft not specifically designed for EVA. The manned maneuvering unit will be used to stabilize the satellite before final rendezvous and capture since the MMS roll rate is beyond the limits of the RMS for grappling. The EVA crewman will also attach an RMS grapple fixture to an MMS trunnion fitting in order to provide the RMS with a more advantageous capability for positioning the MMS on the FSS.

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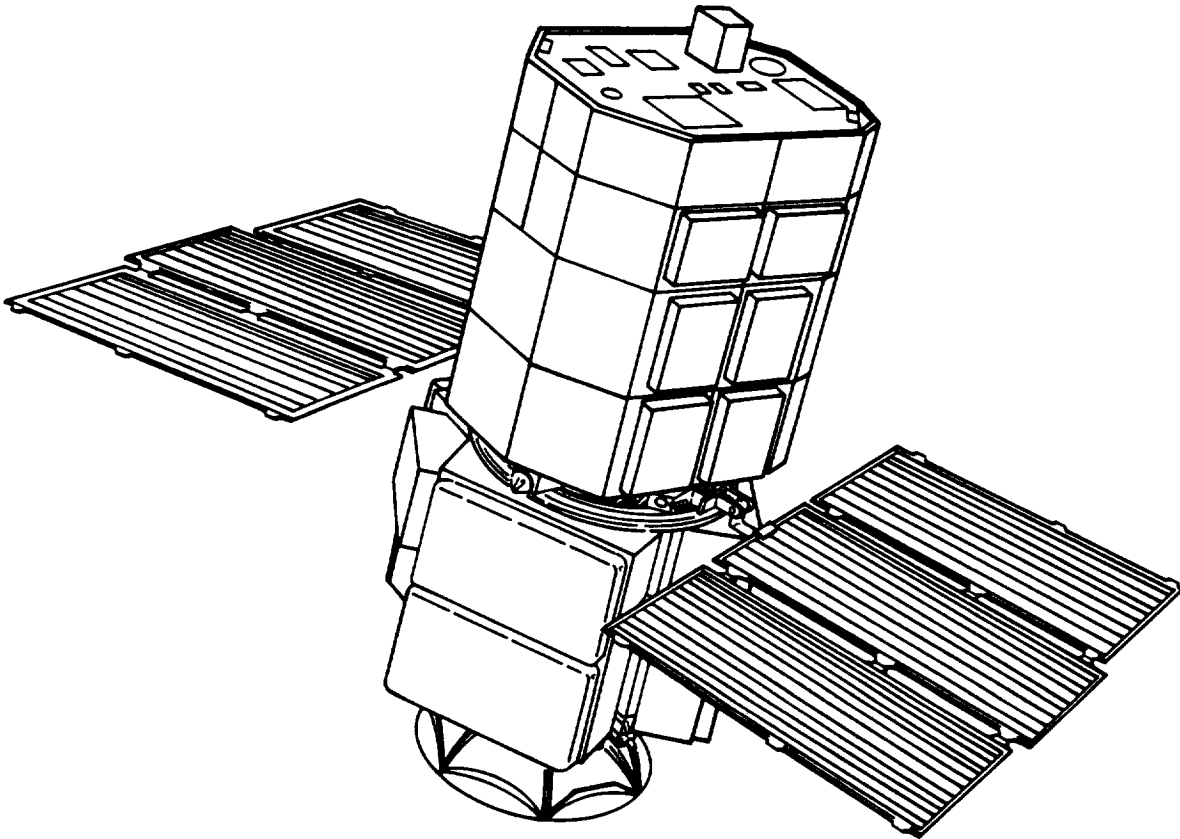


FIGURE I.7-1.— Multimission Modular Spacecraft (SMM).



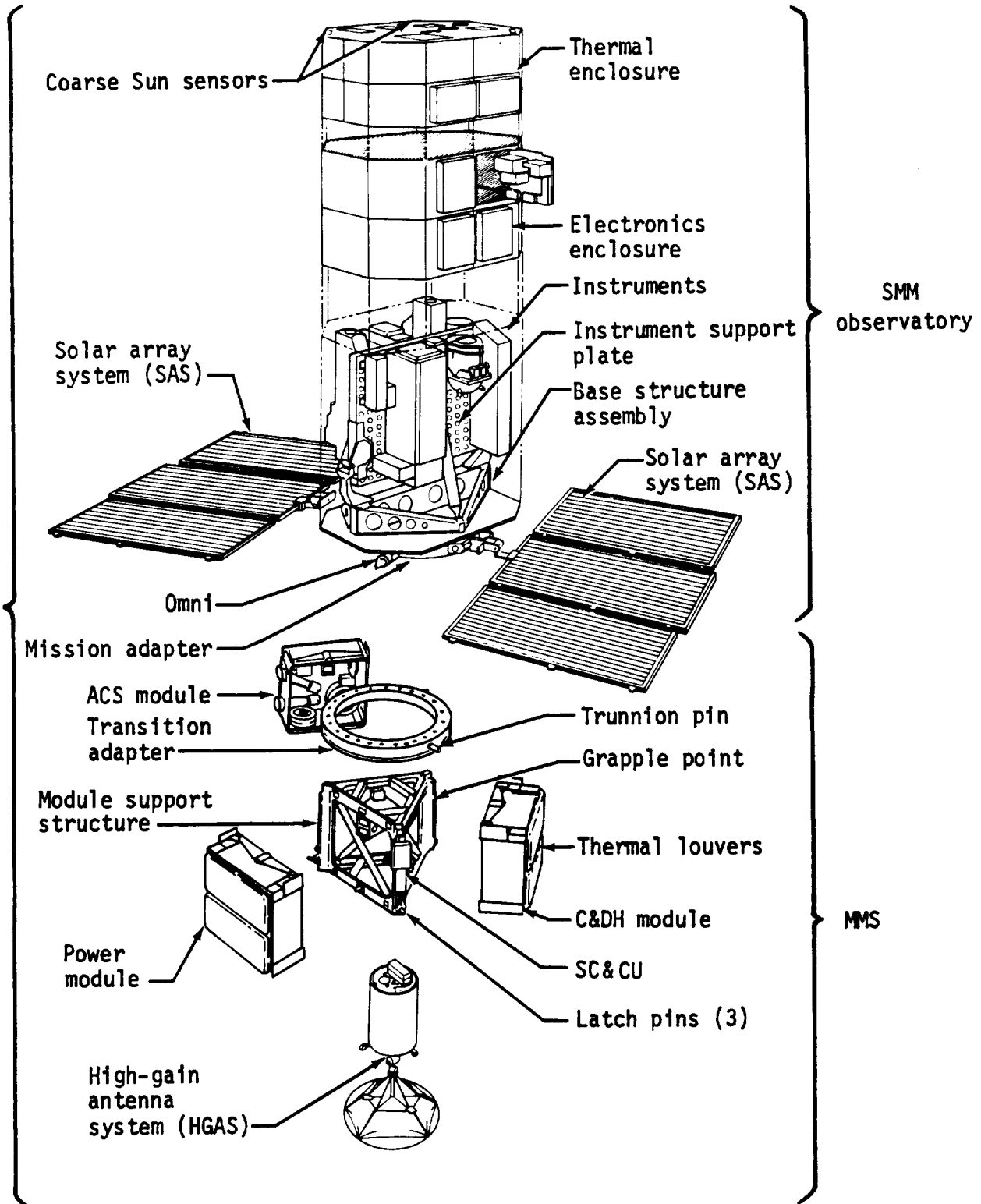


FIGURE I.7-1.— Concluded.

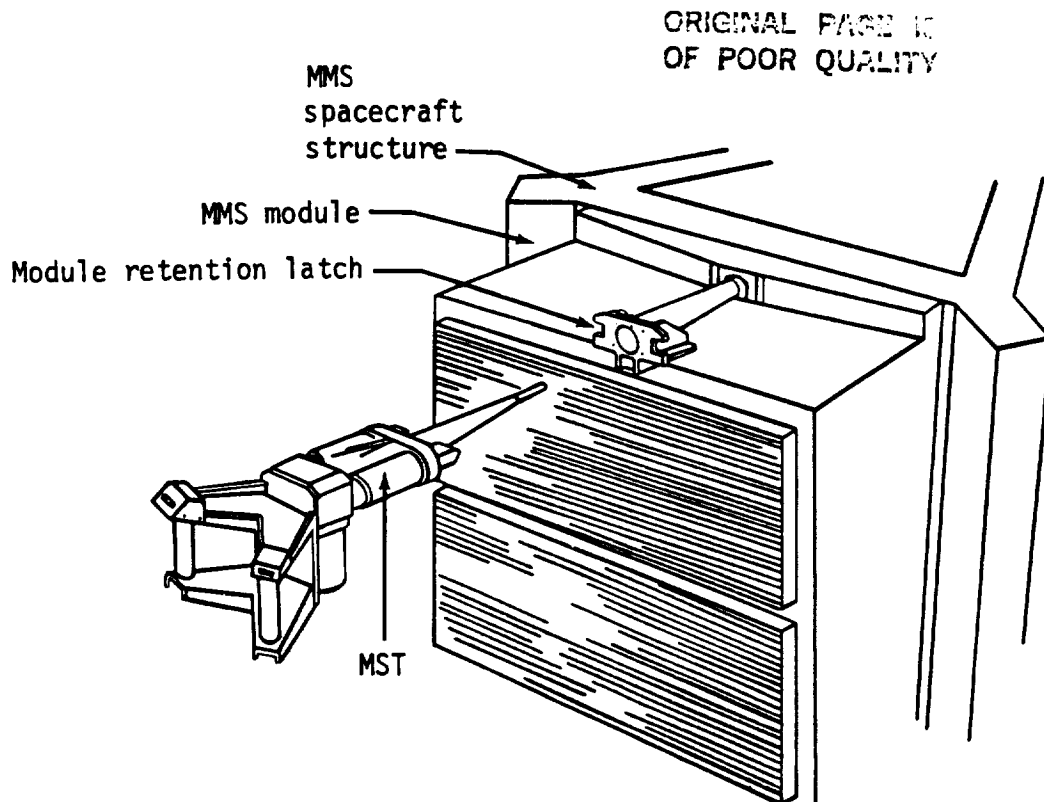


FIGURE I.7-2.— EVA design for module changeout.

A concept being pursued for actual module changeout involves one EVA crewman restrained at the FSS in the portable foot restraint and the second crewman secured in the manipulator foot restraint (fig. I.7-3). The failed module will first be removed from the SMM and secured in a temporary location. The replacement module is then unstowed and secured in the payload handling aids before the MFR is maneuvered between the stowage locations and the MMS worksite.

The module changeout and one of the mission-enhancement tasks both carry a considerable amount of "overhead"; i.e., additional supporting tasks required to accomplish the main objective. These tasks and the amount of additional hardware required result in a complex and time-consuming EVA.

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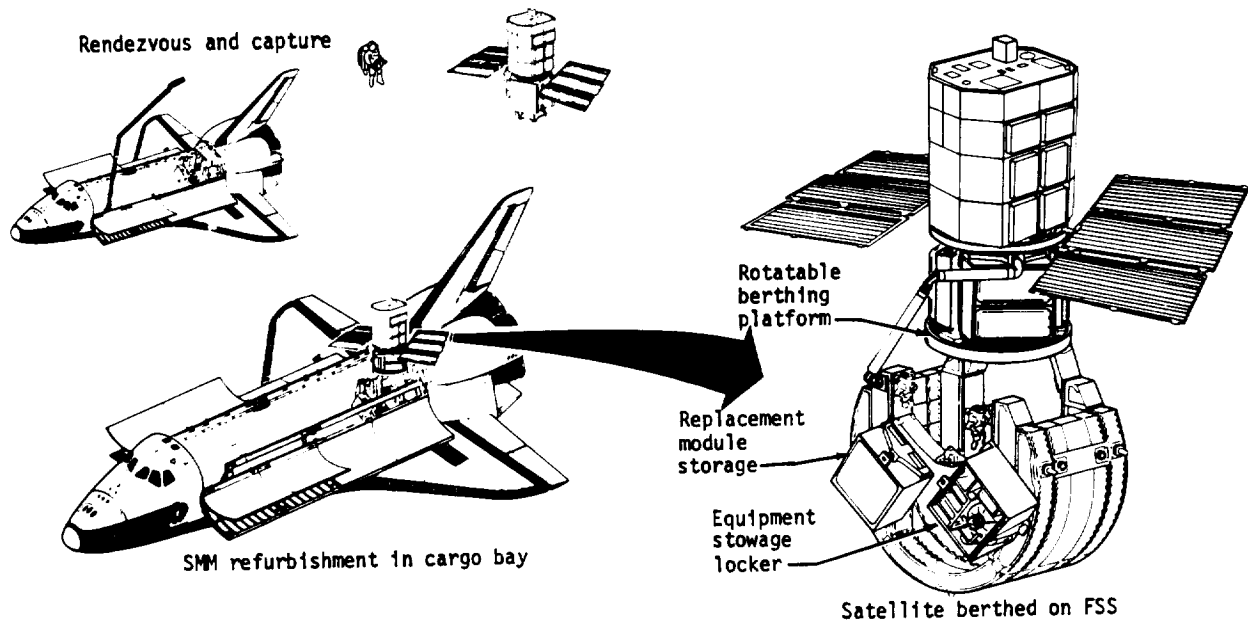


FIGURE 1.7-3.— SMM repair operations.

## 7.2 Space Telescope

The NASA-sponsored Space Telescope (ST) has baselined EVA for a number of planned and unscheduled tasks and has incorporated numerous design features to support it (fig. I.7-4). Most of the planned tasks occur on the maintenance mission, during which the Orbiter revisits the previously deployed ST for the purpose of changing out several orbital replaceable units (ORU's). In both the deployment and the retrieval missions, as well as on the maintenance mission, there are several

possible systems failures which would require unscheduled EVA to override or bypass the failure. Only two representative tasks will be discussed in this section.

The general EVA provisions of the ST include handrails to provide translation to the various worksites, a portable foot restraint with numerous mounting locations, and a standard tool interface at all locations. (One 7/16-inch 12-point deep-well socket on a 3/8-inch drive ratchet wrench (with various length extensions) satisfies all tool require-

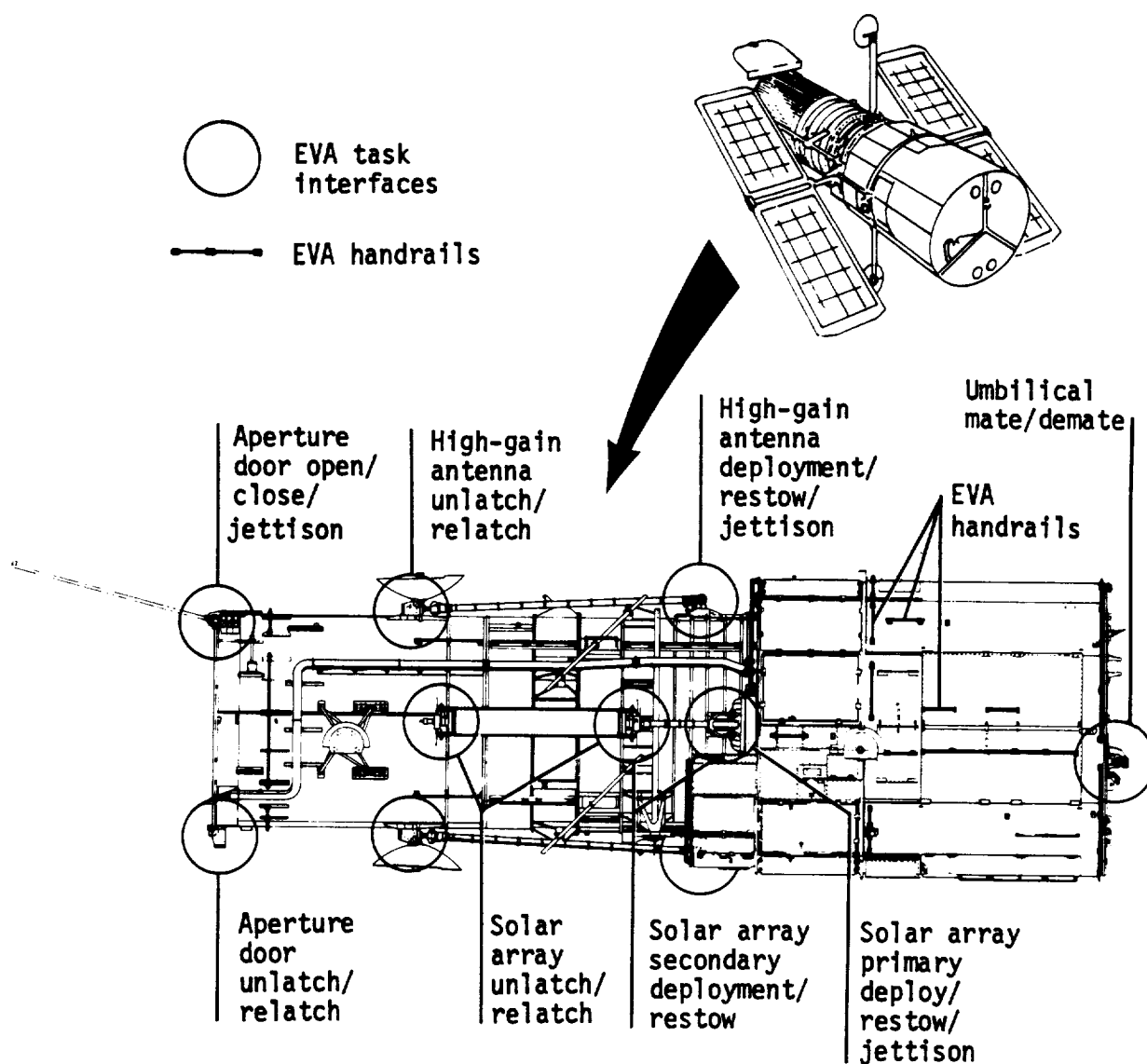


FIGURE I.7-4.— Space Telescope EVA provisions.

ments.) For maintenance and retrieval missions, the ST would be berthed by the RMS on a modified MMS flight support station during EVA, but on the deployment mission, it will be merely held by the RMS approximately 61 centimeters (24 inches) above the payload bay.

**7.2.1 Task description - ORU changeout** — An ORU changeout (fig. I.7-5) would be the typical planned, mission-success task of the ST maintenance mission. During the estimated 15-year life of the ST, various modules may require replacement because of failure or for technical upgrading. All replaceable components are accessible through access doors on the ST support system module aft shroud or equipment section. The smaller boxes are released by first loosening captive bolt fasteners with the 7/16-inch socket wrench and then operating a lead screw, which slides the module back until the fasteners are aligned with the keyholes on the module and all the ganged connectors have been

demated. The ORU is then free to be removed and replaced by the crewman. The larger ORU's will require use of the RMS for transfer and alinement.

**7.2.2 Task description - contingency solar array deployment/stowage** — One of the unscheduled ST tasks on the deployment and maintenance missions is the manual deployment of the solar arrays (SA's) after ST removal from the cargo bay. Failure of either SA to deploy on command will require that the crew go EVA and manually override (1) the stowage latches, (2) the primary drive mechanism to open the array at the hinge point, and/or (3) the secondary drive mechanism to unroll the array. A reverse sequence can be performed to manually restow the arrays. All tasks involve use of the 7/16-inch ratchet; the last involves operating the ratchet tool for approximately 130 complete revolutions of the deployment mechanism, an extremely fatiguing task for the EV crewman despite the low force required. Consequently, a power ratchet tool is under development to support this task with a 34-N-m (25 ft-lb) torque output. The only force required will be to initially install the tool and react to the torque developed.

**7.2.3 Summary of ST EVA tasks** — Appropriate interfaces and support provisions are being provided to support the ST EVA tasks listed in table I.7-1.

**7.2.4 Development efforts** — The ST maintenance mission could require as many as three full 6-hour, two-man EVA's to accomplish the scheduled tasks (fig. I.7-6). Kits will be required to support these planned EVA's and still preserve a two-man EVA capability for Orbiter contingency and an additional capability for ST contingencies. The scope and complexity of the mission requires a correspondingly detailed and extensive development effort to refine hardware configurations and supporting procedures.



FIGURE I.7-5.— ORU changeout evaluation.

TABLE I.7-1.— Space Telescope EVA Tasks

Task	Deployment mission	Maintenance mission	Retrieval mission
ORU changeouts	N/A <sup>a</sup>	pb.c	N/A
Umbilical			
• Demate	U <sup>d</sup>	U	N/A
• Remate	U	U	P
SA deployment			
• Latch	U	U	N/A
• Primary	U	U	N/A
• Secondary	U	U	N/A
SA stowage			
• Secondary	N/A	U	U
• Primary	N/A	U	U
• Latch	N/A	U	U
SA jettison	N/A	U	U
Aperture door			
• Unlatching	U	U	N/A
• Latching	N/A	U	U
• Jettison	N/A	U	U
High-gain antenna (2)			
• Latch	N/A	U	U
• Unlatch	U	U	N/A
• Deployment	U	U	N/A
• Stowage	N/A	U	U
• Jettison	N/A	U	U

<sup>a</sup>N/A = not applicable to that mission.

<sup>b</sup>P = planned.

<sup>c</sup>ORU's will be replaced as required. Twenty-three different modules are capable of being changed out in orbit. No replacement units are carried on the deployment or retrieval missions.

<sup>d</sup>U = unscheduled.

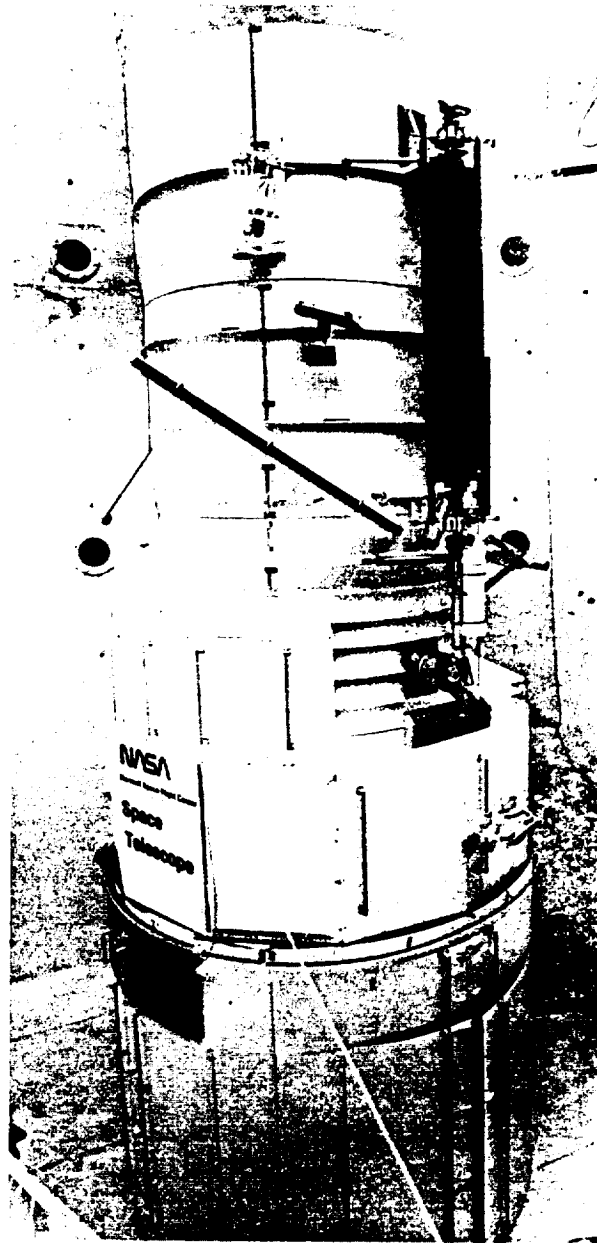


FIGURE I.7-6.— Space Telescope mockup.

### 7.3 Spacelab Scientific Airlock

Extravehicular activity has been selected as the most feasible means to perform safety-critical tasks associated with the Spacelab Scientific Airlock (SAL) (fig. I.7-7). Both the outer hatch and the experiment table of the SAL operate outside the payload envelope while in orbit, and any failure of

either mechanism which prevents it from being properly stowed also prevents the proper closing of the payload bay doors. Both mechanisms are nominally operated by simple mechanical linkages from inside the Spacelab module, and EVA design efforts have focused on providing simple and readily accessible means for jettisoning either one in the event of failure.

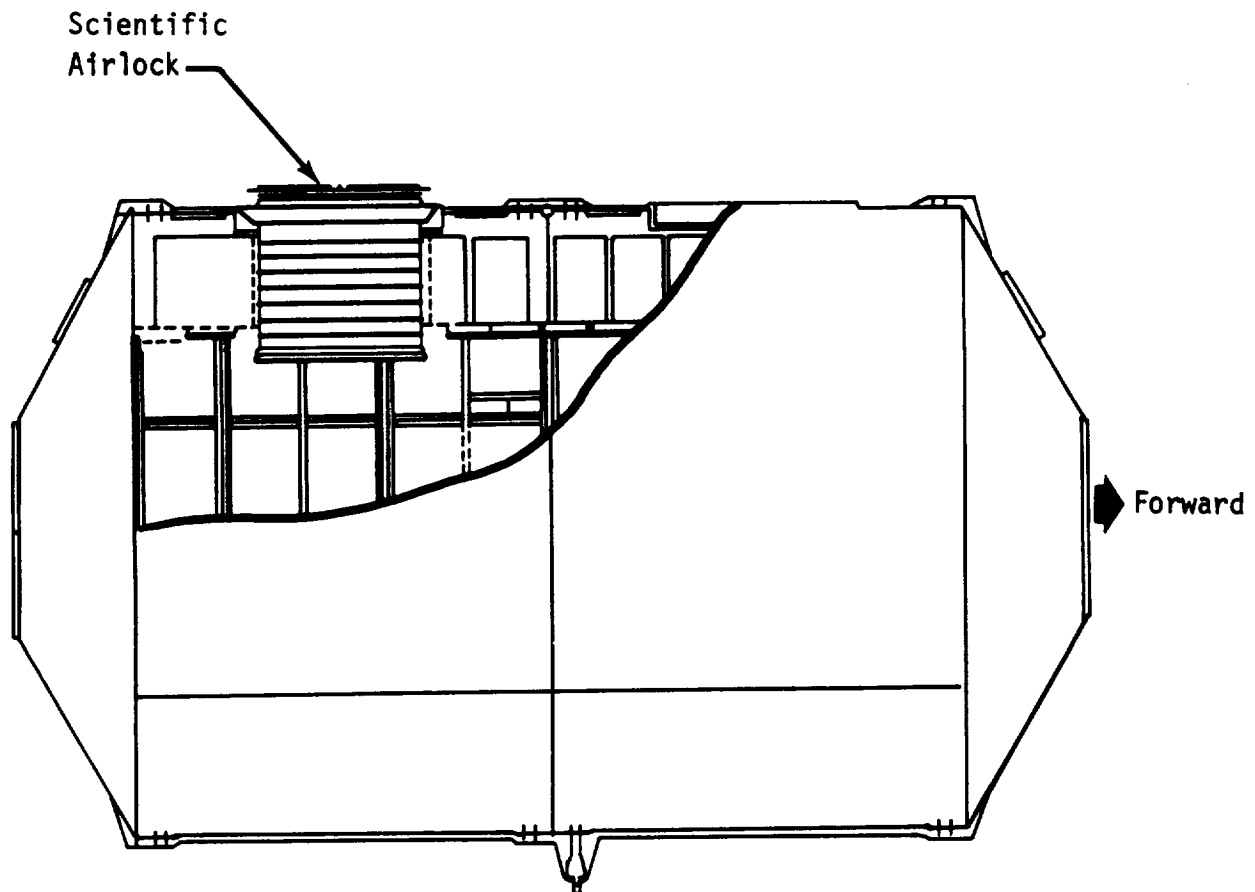


FIGURE I.7-7.— Spacelab Scientific Airlock.

**7.3.1 Task description - outer hatch jettison** — Neither the SAL outer hatch nor the experiment table would be arbitrarily jettisoned by EVA without first attempting to reduce the failure to some operable condition, however degraded it may be. Nominal operation might even be restored, for example, by locating and removing a foreign object jamming the mechanical system. Failing this, the outer hatch upper hinge bracket can be separated from the lower hinge bracket by the removal of four pins. All the pins are withdrawn simul-

taneously by the counterclockwise rotation of the jettison torque tube, which protrudes through the thermal control blankets, by means of a ratchet wrench (fig. I.7-8). After the pins have been retracted, the outer hatch can simply be jettisoned together with the yoke tubes and the upper half of the hinge bracket. The lower half of the hinge bracket, including the pins and jettison torque tube, remains with the SAL. Translation to and restraint at the SAL worksite is provided by handrails mounted on the Spacelab structure.

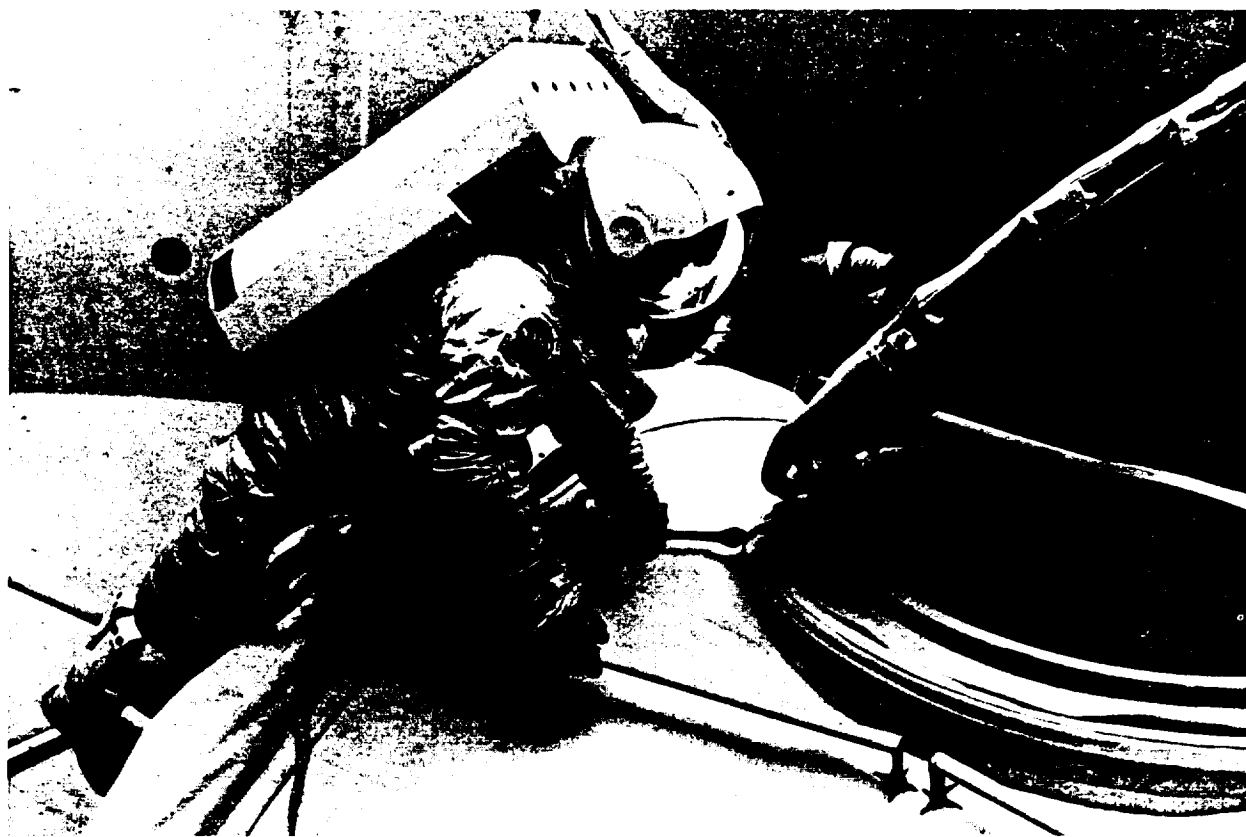


FIGURE I.7-8.— Neutral-buoyancy test - SAL hatch jettison.



*7.3.2 Task description - experiment table jettison —*

The SAL experiment table mechanism consists of fixed, intermediate, and table guide rails which extend by way of interior mechanical linkages to allow exposure of scientific payloads to the space environment. Orbiter fail-safe criteria require that the experiment table have the capability for removal and jettison (fig. 1.7-9) in the event of a failure preventing safe stowage. Removal is ac-

complished by withdrawing two pins which hold the fixed rails in the SAL and demating several electrical connectors to enable the entire structure to be removed and jettisoned. As with the outer hatch, a readily accessible interface is provided to a mechanism which simultaneously accomplishes the pin withdrawal and connector demating operations with a ratchet wrench. Force requirements for both SAL EVA tasks are low.

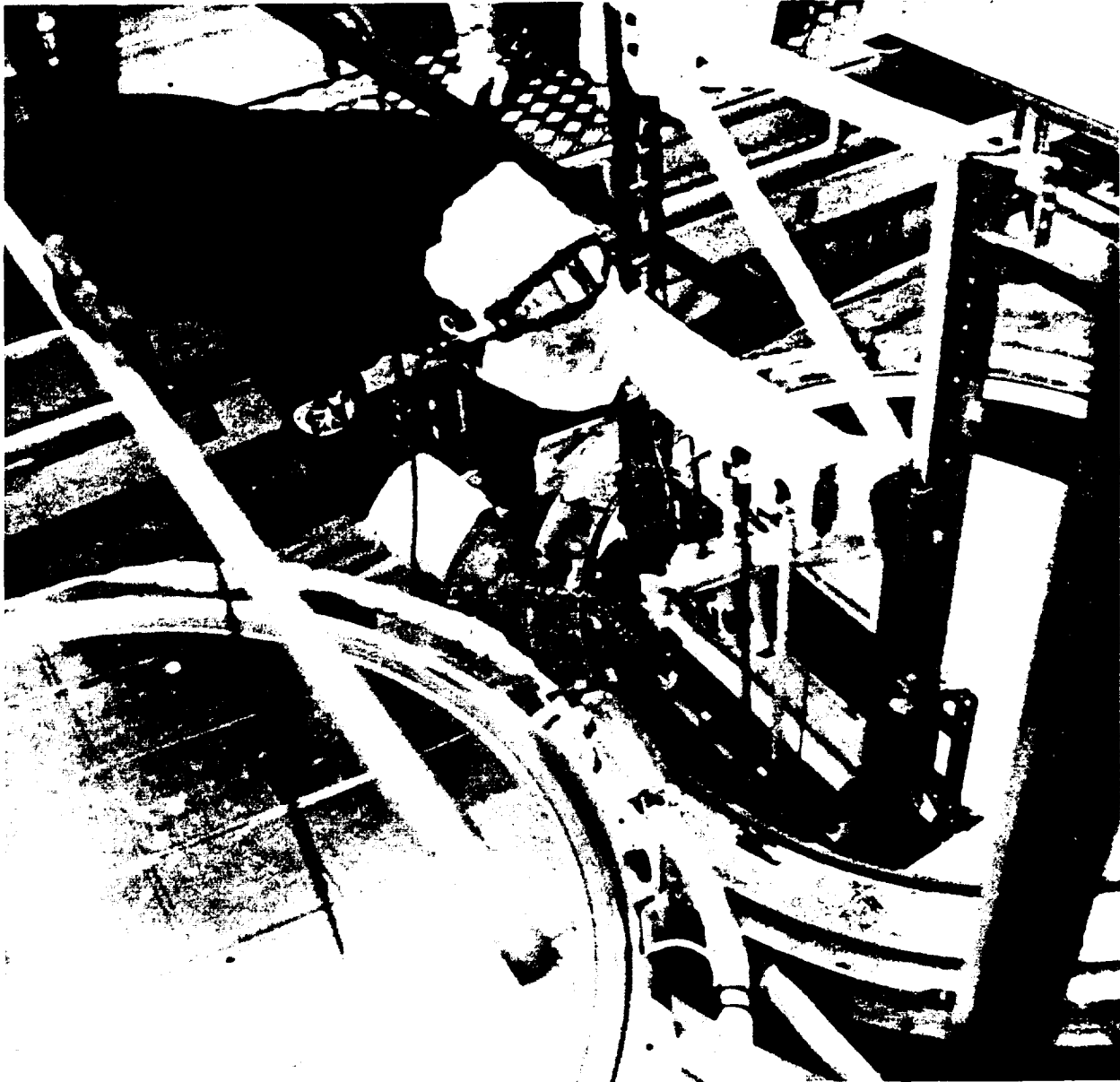
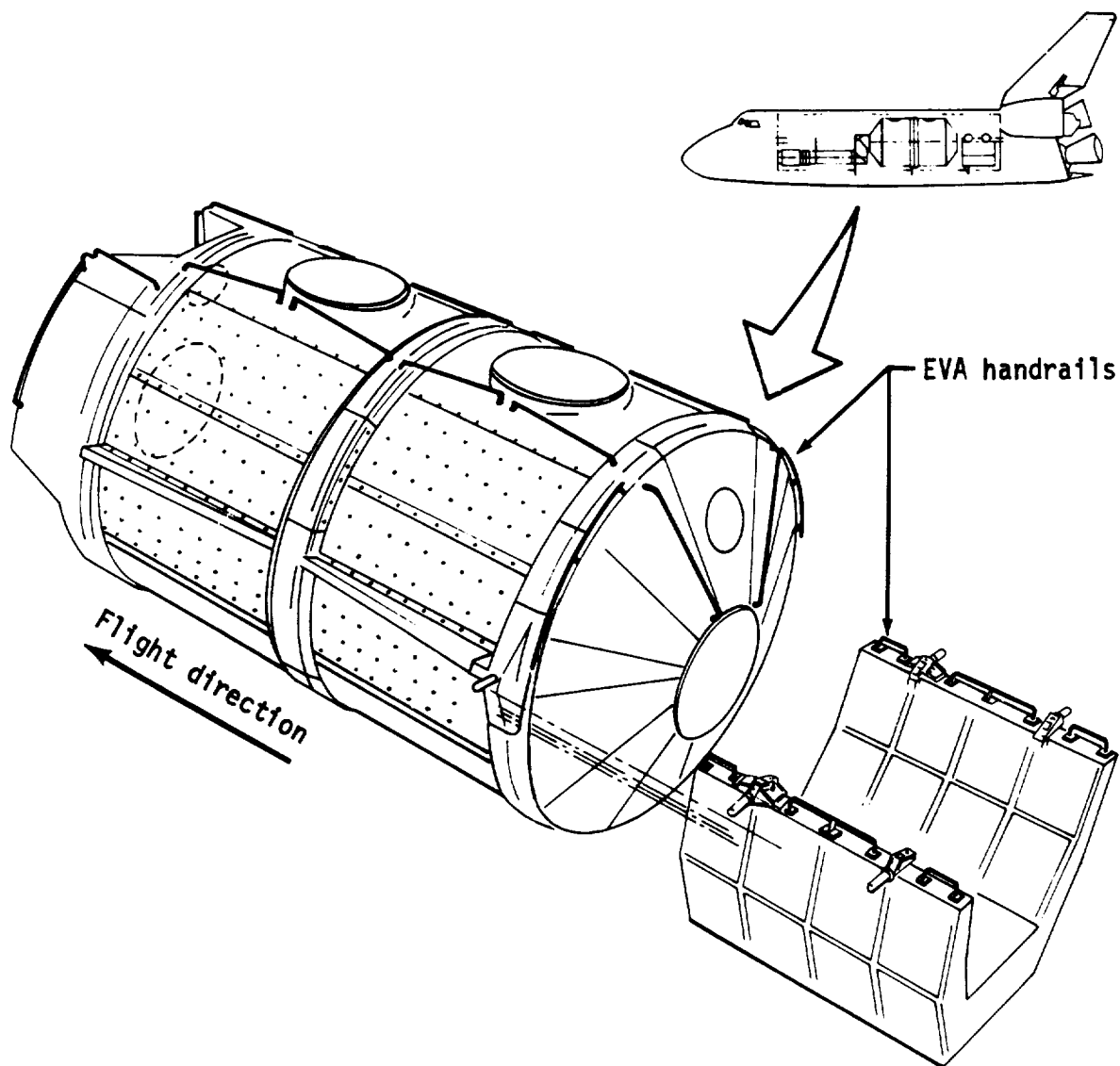


FIGURE 1.7-9.— Design evaluation - experiment table jettison.

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**7.3.3 STS requirements** — For general support of EVA, handrail locations have been baselined for all Spacelab module and pallet configurations as shown in figure I.7-10. These handrails complement those of the Orbiter cargo bay. Despite their relative simplicity, the SAL outer hatch and experiment table jettison tasks remain in the safety-critical

category. Procedure verification and crew training will therefore be accomplished in the JSC Weightless Environment Training Facility (WETF) using a neutral-bouyancy SAL mockup/trainer provided by the payload sponsor with high-fidelity EV interfaces.



**FIGURE I.7-10.— Spacelab EVA handrails.**

#### 7.4 Inertial Upper Stage

The Inertial Upper Stage (IUS) is a two-stage solid rocket booster system designed to place a 2268-kilogram (5000 pound) payload into a geosynchronous orbit. Nominally, the IUS, with its attached payload (fig. 1.7-11), is erected into its proper launch configuration in the Orbiter payload bay and separated by firing a pyrotechnic release device, which allows six springs to deploy the IUS from the frame. The IUS is ignited after the Orbiter moves to a safe distance.

Two potential failures would require EVA: (1) the primary aft frame tilt actuator (AFTA) fails and also fails to decouple or (2) the primary AFTA fails and the secondary actuator subsequently fails. These failures can be considered safety critical when the IUS/spacecraft has been erected but not launched, a situation which would prevent payload bay door closing.

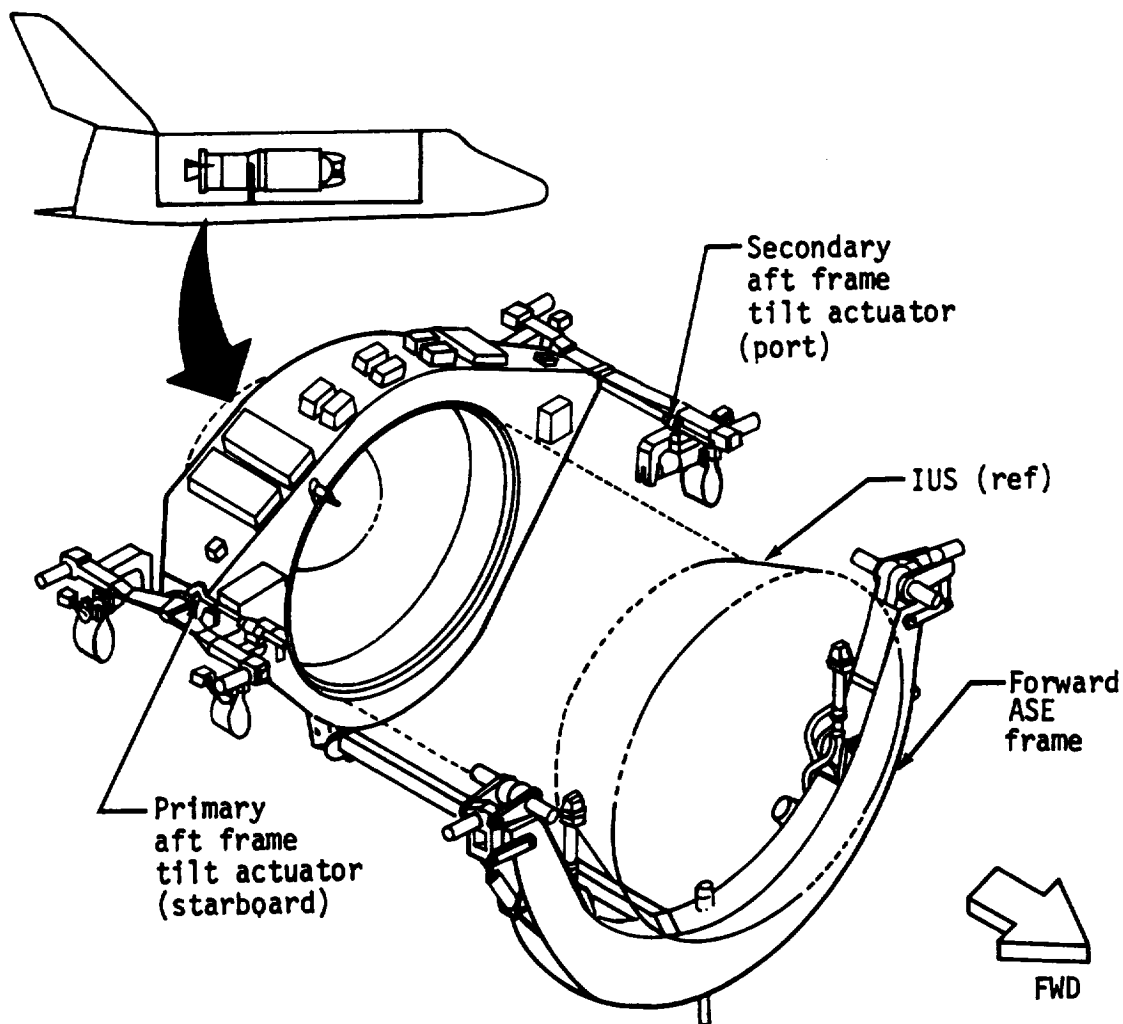


FIGURE 1.7-11.— IUS airborne support equipment.

**7.4.1 Task description - decoupling of AFTA** — The starboard AFTA has a pyrotechnic pin puller which, disengages the primary AFTA from the frame assembly in the case of failure, allowing the portside AFTA to position the frame for IUS deployment or reberthing in the bay. Both port and starboard AFTA's have a backup means for an EVA crewman to accomplish the disengagement (fig. I.7-12). After removing a spring keeper, which

remains tethered to the mechanism, the 7/16-inch socket and ratchet handle are used to rotate a jackscrew approximately 10-1/4 turns, which forces the lockpin out of engagement with the slipring and releases the AFTA. Torque required is on the order of 21.6 N-m (16 ft-lb). Access to the work areas, which are only 25 centimeters (10 inches) inboard of the payload bay sill longerons, is from the top with the doors open.

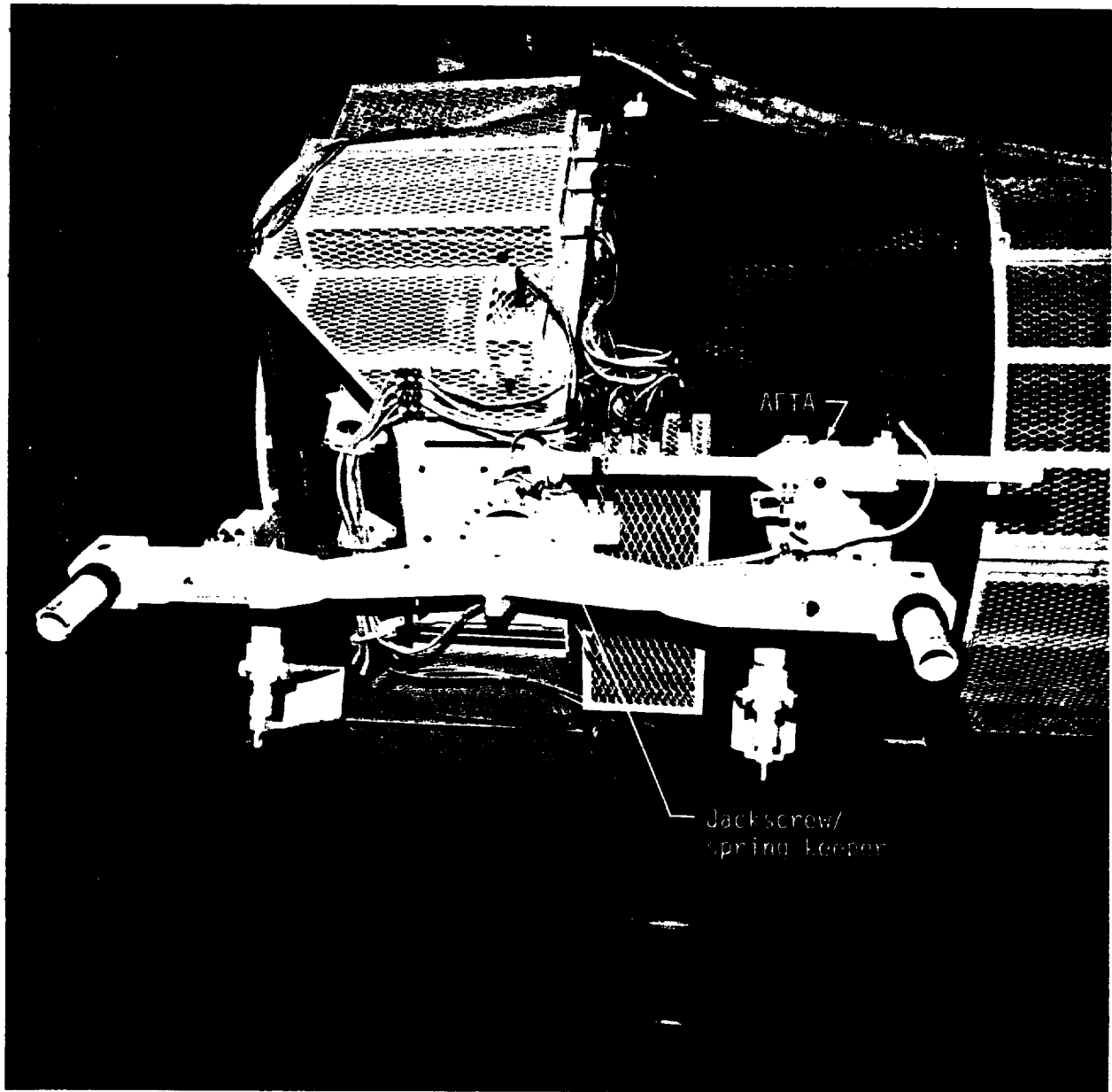


FIGURE I.7-12.— IUS trainer EVA interfaces - primary AFTA.

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**7.4.2 Task description - manual stowage of IUS airborne support equipment** — When both AFTA's have failed to function and the airborne support equipment (ASE) frame is in other than its stowed position, it is necessary to manually stow the ASE using the Orbiter EVA winch mounted on the aft bulkhead of the payload bay. This task is safety critical in that the unstowed IUS/payload can interfere with cargo bay door closing and even the unsecured empty ASE frame could cause Orbiter damage during landing.

The first step is to route the rope from the EVA winch through an Orbiter-provided pulley and connect the hook to a fitting on the aft side of the ASE. The hook support is at one end of a tube assembly

which is positioned to provide the necessary mechanical advantage for the manual operation (fig. I.7-13). The tube assembly deployment involves pulling a spring-loaded T-handle outboard to release it from its stowed position. The work envelope for this operation is from above the IUS cradle at the aft payload bay bulkhead with a minimum clearance of 112 centimeters (44 inches) between the bulkhead and the ASE in the worst case position.

Actual repositioning of the tilt assembly, especially with the IUS/payload present, will involve visual and verbal coordination between the EV and IV crewmembers to verify position and rate of movement.

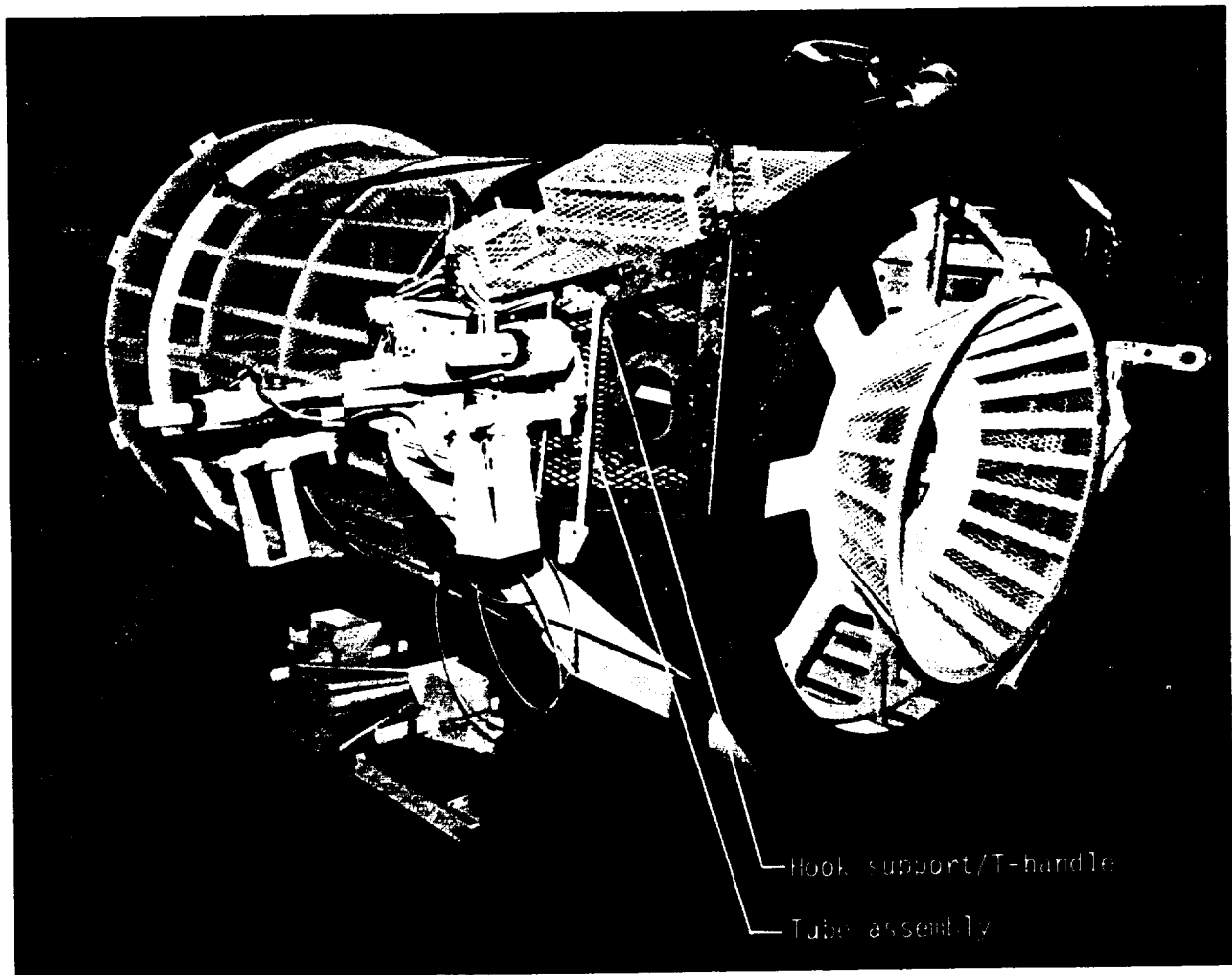


FIGURE I.7-13.— IUS trainer EVA interfaces - aft ASE.

7.4.3 *STS requirements* — Because this payload carrier will be flown on several missions and because its possible failures can be classified as safety critical, considerable effort is being devoted to IUS EVA procedures (fig. I.7-14). A full-scale

neutral-bouyancy mockup, including a volumetric representation of the payload and high-fidelity mechanical interfaces for the EVA tasks, is under development.

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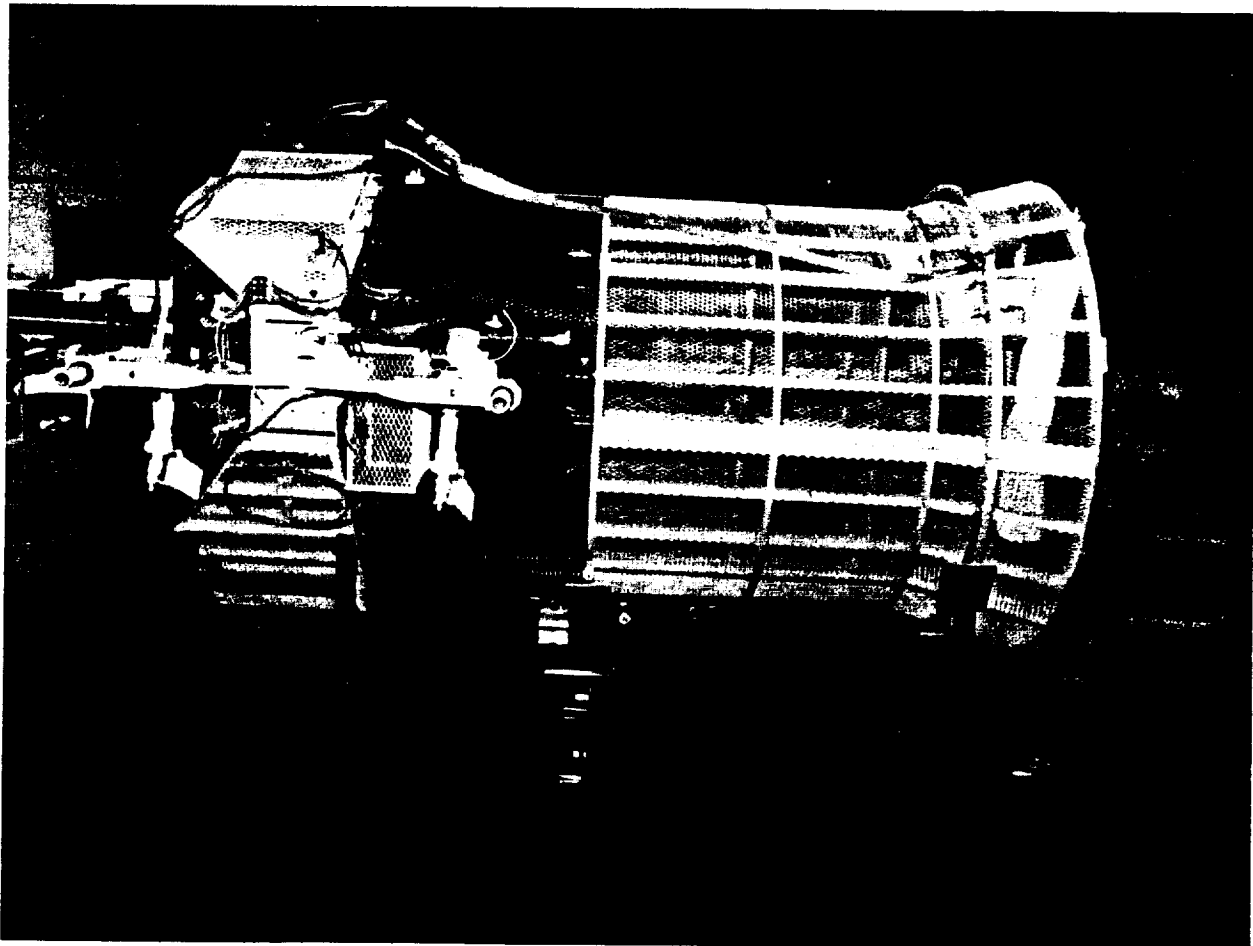


FIGURE I.7-14.— IUS neutral-buoyancy trainer (less spacecraft).

### 7.5 Shuttle Orbiter

Several possible failure modes in the various payload bay mechanical systems can be repaired or bypassed by EVA. All such tasks are in the safety-critical category as any one of these failures could prevent safe return of the vehicle. As is often the case with a contingency task, the EVA require-

ments were applied to the affected systems so late in the design and fabrication efforts that little opportunity existed to design EVA capability into the mechanisms themselves. Consequently, the procedures and the supporting hardware were developed to work around the existing configurations (fig. I.7-15). The criticality of the tasks, as well as their complexity, has required a significant

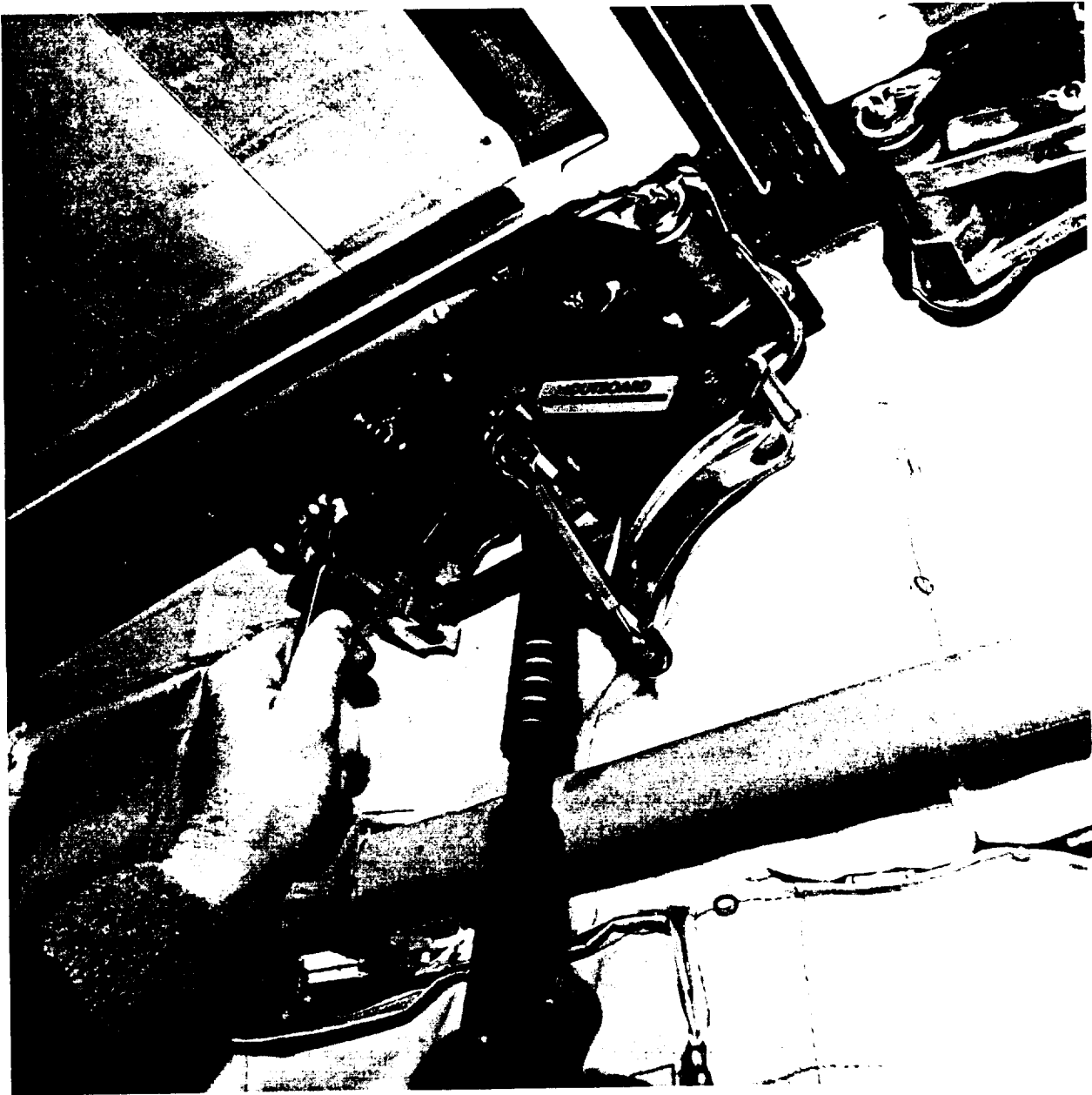


FIGURE I.7-15.— Bulkhead door latch bypass tool.

commitment of resources to hardware and procedures development including reiterative evaluation exercises and an extensive astronaut training program to achieve a very high probability of success regardless of the low probability of occurrence. Since this training is required for each crew, it is also used as the vehicle for achieving proficiency in generic EVA techniques (translation, use of restraints, equipment and tether management, etc.), providing the departure point for mission-specific EVA training. Procedures have been developed and provisions made to accomplish the tasks listed in table I.7-2.

**7.5.1 Procedures and hardware development** — The primary supporting elements in the continuing efforts to develop the techniques, procedures, and supporting hardware for the Orbiter contingency tasks have been the numerous evaluation exercises using actual Orbiter development and test articles, the Orbiter itself, and the neutral-bouyancy trainers. Pressure-suited subjects test and evaluate

hardware and procedure concepts on high-fidelity representations of flight hardware until both are refined enough to begin crew training (fig. I.7-16). The full-scale payload bay mockup in the JSC WETF provides the environment for end-to-end EVA task training in neutral bouyancy.

**7.5.2 Mission integration** — The nature of the Orbiter contingency EVA tasks, especially with regard to their most probable time of occurrence and the relationship between the failures and the Orbiter's capability to remain in orbit, has required careful planning to ensure that all the EVA requirements are satisfied without precluding any other activities that are necessary to support EVA, to stay in orbit long enough to perform the EVA, or to preserve the required deorbit opportunities. Consequently, separate time lines were developed to govern crew activities from the time a failure which required EVA occurred until normal orbital operations or activities in the nominal deorbit time line could be resumed.

TABLE I.7-2.— Shuttle Orbiter EVA Tasks

<i>Failure</i>	<i>Procedure</i>	<i>Support provisions</i>
Mechanical jam, all systems	Locate and remove jam	Jam removal tools
Radiator drive failure	Disconnect radiator drive assembly, manually stow	Drive mechanism shear pin 3/8-in. ratchet 3/8-in. extension with 1/4-in. hex head
Payload bay door drive failure	Disconnect power drive unit (PDU) or Cut door drive linkages (6)  then Manually close door	PDU disconnect tool  Tube cutter Restraint tape  EVA winches (2)
Bulkhead latch failure	Install latch bypass tool(s)	Three-point bulkhead latch tools (8) Portable foot restraint with adjustable boom
Centerline latch failure	Install centerline latch bypass tool	Centerline latch bypass tools (4) Portable foot restraint with centerline clamp
Airlock latch failure	Disconnect latch(es) from actuator	3/8-in. ratchet with 7/16-in. socket Adjustable wrench EVA removable bolts (11 per hatch)



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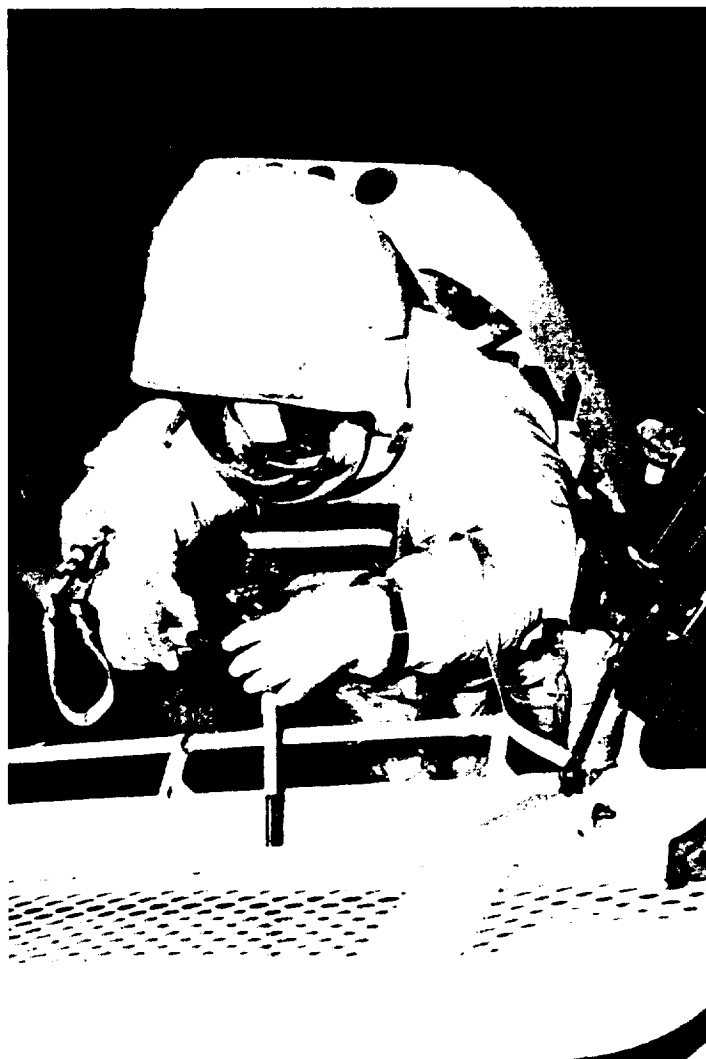


FIGURE I.7-16.— Radiator drive disconnect evaluation.



## Appendix A - List of Available EVA Equipment

This list includes all items of equipment developed to support STS EVA that may have payload applications. Payload EVA equipment requirements will be identified in PIP Annex 11. Inclusion in the manifest of items not otherwise baselined will render them chargeable to the payload. Roman numerals in parentheses after each item name indi-

cate expected manifesting as follows.

- I Expected baseline
- II Expected for mission configuration indicated (e.g., Spacelab, RMS, etc.)
- III Payload chargeable
- IV To be determined

### A-1

Item: Extravehicular mobility unit (EMU) (I)

Quantity: Two

Part number: (Several)

Weight: 113.34 kilograms (249.88 pounds)

Stowage: Airlock

Remarks: Provides environmental protection, mobility, life support, and communications for crew operations outside pressurized compartment. Weight is for one charged EMU. Baseline also includes sufficient consumables and support or ancillary equipment to provide three two-man, 6-hour EVA's. Spare items are listed separately below. Support equipment includes, in part, the following.

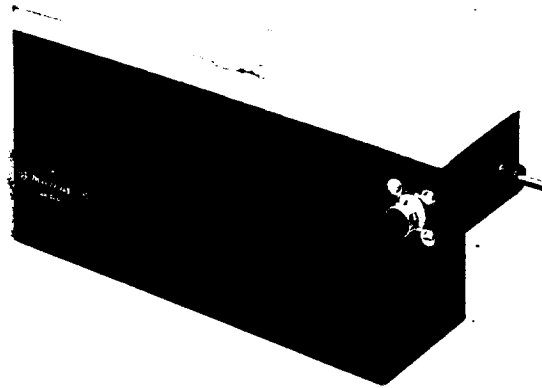
Item	Quantity	Stowage
Mini work station	1 each/EMU	Mid-deck or cargo bay
Wrist tethers	2 each/EMU	Airlock (EMU)
Waist tethers	2 each/EMU	Airlock (EMU)
EVA scissors	1 pair/EMU	Airlock (EMU)
Cuff checklist	1 assembly/EMU	Mid-deck
EV glove hot pads	1 pair/EMU	Cargo bay
15.2-m (50 ft) safety tether	2	Cargo bay



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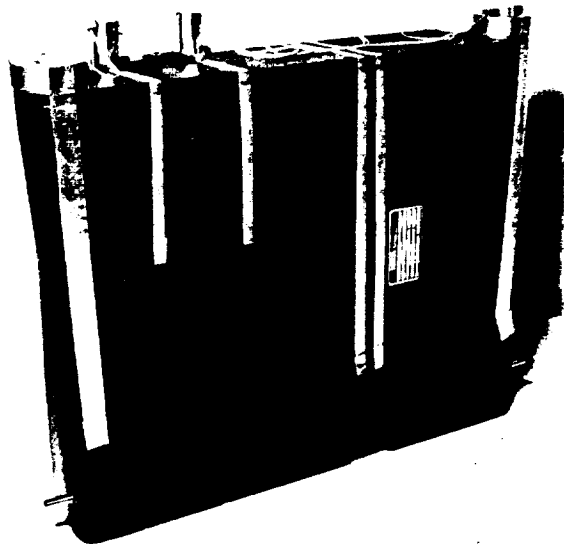
**A-2**

Item: EMU battery (III)  
Quantity: As required  
Part number: SV767789-02  
Weight: 4.45 kilograms (9.80 pounds)  
Stowage: Mid-deck lockers  
Remarks: Additional battery for multiple EVA's  
where on-orbit recharging is impractical.



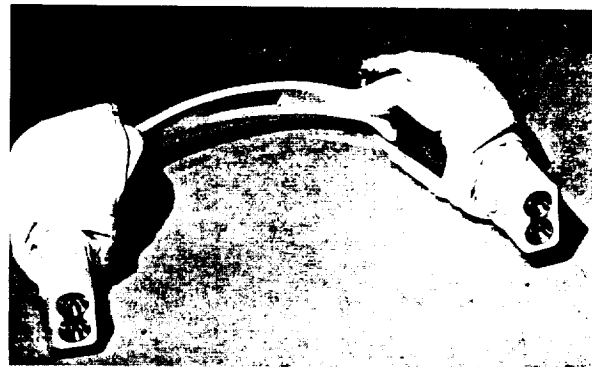
**A-3**

Item: EMU LiOH canister (III)  
Quantity: As required  
Part number: SV767790-03  
Weight: 2.88 kilograms (6.36 pounds)  
Stowage: Mid-deck lockers  
Remarks: One canister per EMU per EVA is required for CO<sub>2</sub> scrubbing of suit ventilation flow.



**A-4**

Item: EMU lights (I)  
Quantity: Two (one assembly/EMU)  
Part number: 10161-10061-02 (assembly)  
Weight: 2.63 kilograms (5.79 pounds) (assembly with six batteries)  
Stowage: Mid-deck lockers  
Remarks: Mounts on EMU helmet visor to provide lighting at worksite. One battery conditioner is also flown. Each pair of batteries is good for one EVA, and they are not rechargeable on orbit. Light assembly also provides mounting point for EMU-TV.



**A-5**

Item: EMU light battery (III)

Quantity: As required

Part number: 10161-20001-01

Weight: 0.15 kilogram (0.34 pound) each

Stowage: Mid-deck

Remarks: Two batteries per EMU light assembly are required for each EVA beyond three baselined.

**A-6**

Item: EMU-TV system (II - planned EVA)<sup>1</sup>

Quantity: One

Part number: SED 18100247-303 (camera, transmitter assembly)

Weight: 13.38 kilograms (29.50 pounds)

Stowage: Mid-deck lockers

Remarks: Provides real-time video input to Orbiter CCTV system from EV crewmember at worksite. The camera field of view is 32° horizontally and 25° vertically. The normal depth of field is from 81 centimeters (32 inches) to approximately 7.6 to 9 meters (25 to 30 feet) depending on lighting, but is adjustable down to 30 centimeters (12 inches) while EVA. Transmission to the Orbiter is good from ranges of at least 152 meters (500 feet). Weight listed above is total for camera-transmitter unit, one battery pack, and mid-deck receiver unit.



**A-7**

Item: EMU-TV battery pack (III)

Quantity: As required

Part number: 10160-20001-02

Weight: 1.18 kilograms (2.60 pounds)

Stowage: Mid-deck lockers

Remarks: Spare batteries for EMU-TV. One battery pack is sufficient for one EVA.



<sup>1</sup>EMU-TV system is intended to be flown for all planned EVA's. If EVA is for payload, EMU-TV is payload chargeable.

**A-8**

Item: Adjustable wrist tethers (I)

Quantity: Two

Part number: 10159-20005-02

Weight: 0.26 kilogram (0.57 pound)

Stowage: Cargo bay

Remarks: Similar to wrist tethers stowed on EMU.

Adjustable from 12.7 centimeters (5 inches) to  
40.64 centimeters (16 inches).



**A-9**

Item: Portable foot restraint system (I)

Quantity: One

Part number: 10155-20005-01 (platform)

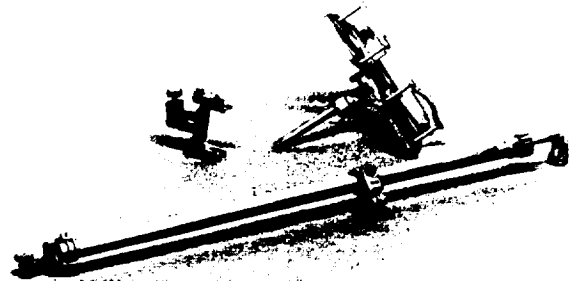
10155-20006-03 (clamp assembly)

10155-20003-01 (boom assembly)

Weight: 13.80 kilograms (30.43 pounds)

Stowage: Cargo bay

Remarks: The PFR system consists of one adjustable foot restraint platform, two boom assemblies with clamps, and one centerline clamp. Boom assemblies are extendable from 1.73 meters (68.07 inches) to 2.44 meters (96.0 inches) and can be attached to any standard handrail. Crew-induced loads through the boom are limited to 81.3 N-m (60 ft-lb) torque. Clamp assemblies provide a receptacle for the platform extension arm. Inside diameter of clamp assembly is 5.08 centimeters (2.0 inches).

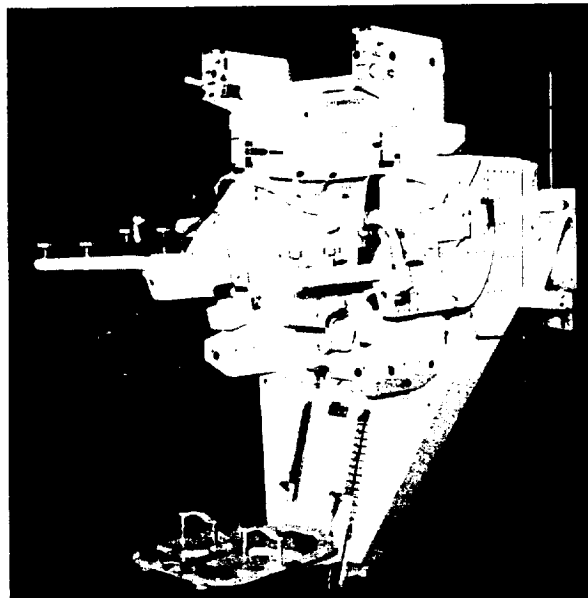


**A-10**

Item: Manipulator foot restraint (MFR) (IV)  
Quantity: One  
Part number: TBD  
Weight: TBD  
Stowage: Cargo bay  
Remarks: Provides restrained access to EVA worksites within reach of RMS. Has mounting provisions for tools and temporary stowage of equipment. Developmental. Weight cited includes stowage provisions in cargo bay. Does not rigidize with the worksite; upper limits of induced loads through RMS are TBD. Control of MFR is by RF voice link to RMS operator in cabin.

**A-11**

Item: Manned maneuvering unit (III)  
Quantity: As required  
Part number: 852 MU 000000-009  
Weight: 147.42 kilograms (325 pounds)  
Stowage: Cargo bay  
Remarks: Provides untethered translation capability for one EVA crewman beyond confines of cargo bay. As many as two MMU's can be stowed in bay, each requiring a 68.04-kilogram (150.0 pound) flight support station. Uses  $\text{GN}_2$  propellant, reserviceable from Orbiter via the FSS.



**A-12**

Item: Tool caddy (IV)

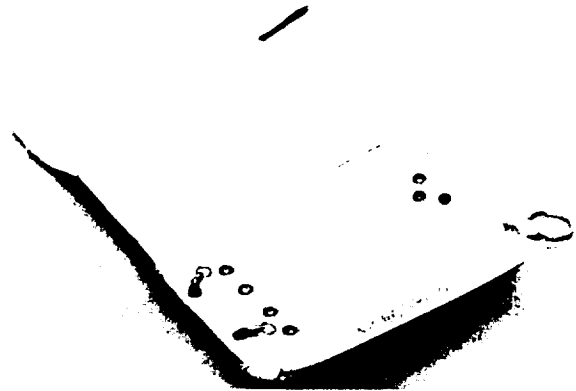
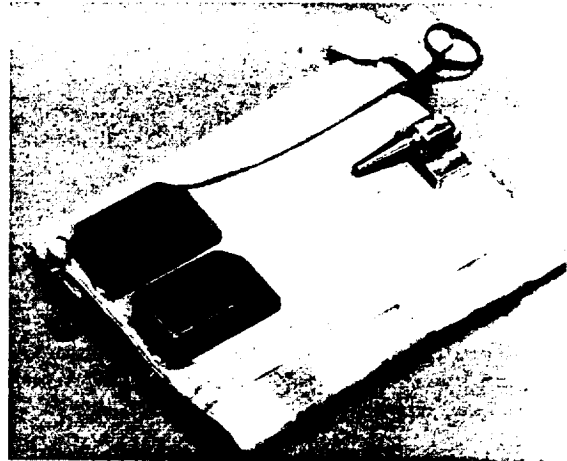
Quantity: As required

Part number: V628-650994-014

Weight: 0.85 kilogram (1.88 pounds)

Stowage: As required

Remarks: Tool caddy is a stiffened fabric container for small EVA handtools. It incorporates two 0.91-meter (3 foot) retractable tethers and pile Velcro strips for retention of tools, and can be mounted on the mini work station.



**A-13**

Item: Adjustable wrench (I)

Quantity: Two

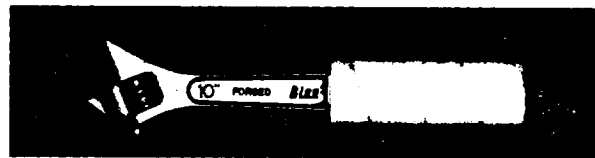
Part number: V628-650892-004

Weight: 0.45 kilogram (0.99 pound)

Stowage: Cargo bay (tool caddy)

Remarks: Common tool modified for EVA use.

Maximum opening is 2.84 centimeters (1.12 inches).

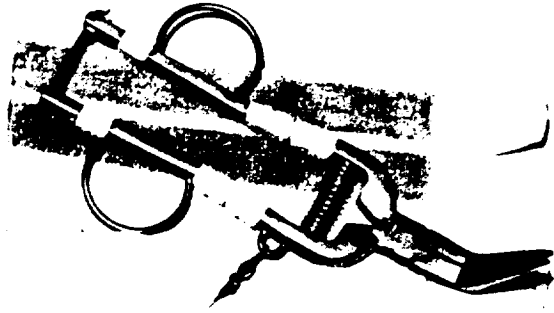




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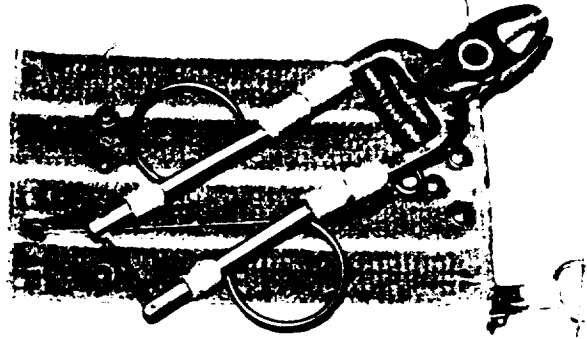
**A-14**

Item: 90° needle nose pliers (I)  
Quantity: One  
Part number: V628-650865-001  
Weight: 0.27 kilogram (0.6 pound)  
Stowage: Cargo bay  
Remarks: Common tool modified for EVA use.



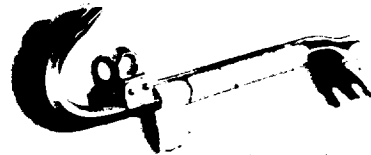
**A-15**

Item: Diagonal cutters (I)  
Quantity: One pair  
Part number: V628-650866-001  
Weight: 0.27 kilogram (0.6 pound)  
Stowage: Cargo bay  
Remarks: Common tool modified for EVA use.



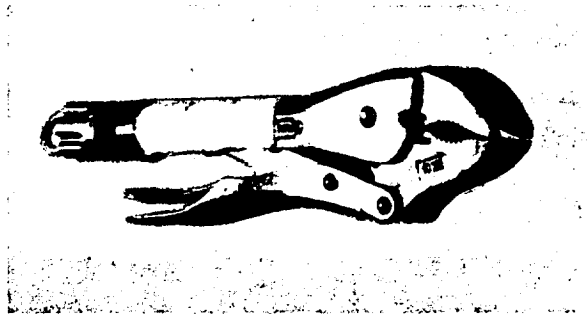
**A-16**

Item: Bolt puller (I)  
Quantity: One  
Part number: V628-650880-007  
Weight: 0.36 kilogram (0.8 pound)  
Stowage: Cargo bay  
Remarks: Common crowbar modified to accommodate EVA and to improve leverage in confined spaces.



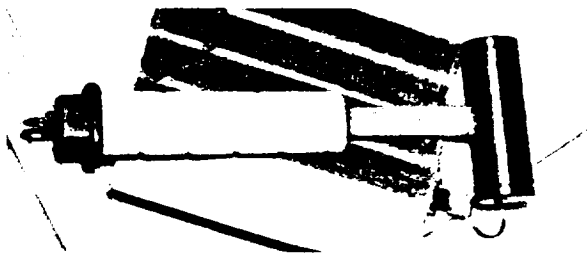
**A-17**

Item: Vise grips (I)  
Quantity: One pair  
Part number: V628-650876-001  
Weight: 0.55 kilogram (1.2 pounds)  
Stowage: Cargo bay  
Remarks: Common tool modified for EVA use.



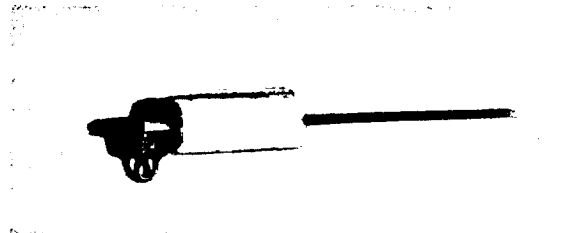
**A-18**

Item: Hammer (I)  
Quantity: One  
Part number: V628-650875-004  
Weight: 0.91 kilogram (2.0 pounds)  
Stowage: Cargo bay  
Remarks: Brass-head hammer modified for EVA use.



**A-19**

Item: Probe (I)  
Quantity: One  
Part number: V628-650879-004  
Weight: 0.27 kilogram (0.6 pound)  
Stowage: Cargo bay  
Remarks: Screwdriver-type tool, 0.48-centimeter (0.188 inch) diameter tip, 21.91 centimeters (8-5/8 inches) long.



**A-20**

Item: Lever wrench (II)  
Quantity: One  
Part number: V628-650878-003  
Weight: 0.68 kilogram (1.5 pounds)  
Stowage: Cargo bay  
Remarks: Common tool modified for EVA use.



**A-21**

Item: 3/8-inch EVA ratchet drive (IV)

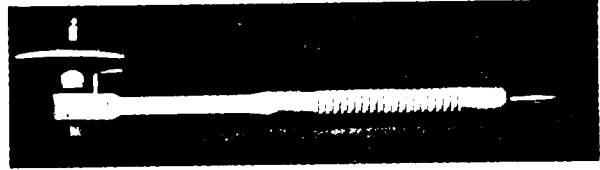
Quantity: One

Part number: ESEX-82-27-10

Weight: 0.54 kilogram (1.18 pounds)

Stowage: Cargo bay

Remarks: 3/8-inch ratchet drive specially designed for EVA use. Handle is used to apply "breakout" force; "mushroom" disk is turned by hand where overtorquing needs to be avoided, or where resistance is insufficient to operate ratchet. Developmental.



**A-22**

Item: EVA screwdriver (IV)

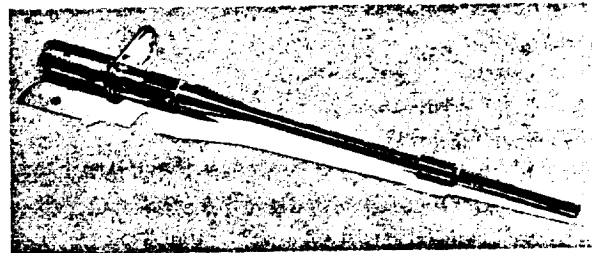
Quantity: One

Part number: SED 33102672-301

Weight: 0.18 kilogram (0.4 pound)

Stowage: Cargo bay

Remarks: Shrouded screwdriver, 22.86 centimeters (9 inches) long, compatible with 3/8-inch EVA ratchet drive. Developmental.



**A-23**

Item: EVA Allen wrench (IV)

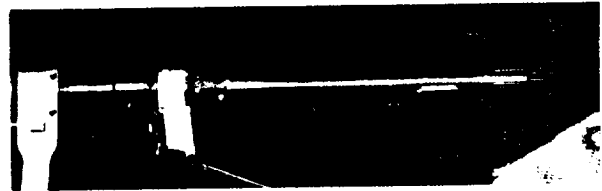
Quantity: One

Part number: SED 33102671-301

Weight: 0.18 kilogram (0.4 pound)

Stowage: Cargo bay

Remarks: Number 10 Allen wrench, 22.86 centimeters (9 inches) long, compatible with 3/8-inch EVA ratchet drive. Tool has a movable sleeve sized to capture number 10 Allen head capscrew. Developmental.



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**A-24**

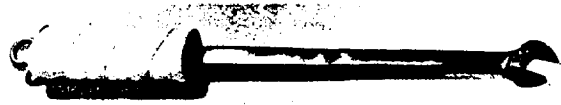
Item: EVA power ratchet (IV)  
Quantity: TBD  
Part number: TBD  
Weight: TBD  
Stowage: Cargo bay  
Remarks: Developmental. Tool is electrically  
powered 3/8-inch ratchet drive; ideal for low-  
force, high-revolution tasks. Availability TBD.

**A-25**

Item: 7/16-inch socket/4-inch extension/3/8-inch  
ratchet drive (I)  
Quantity: One  
Part number: V628-650860-  
Weight: 0.45 kilogram (1.0 pound)  
Stowage: Cargo bay  
Remarks: Common tool modified for EVA use.  
Socket, extension, and drive are pinned together.

**A-26**

Item: 1/2-inch open-end wrench (I)  
Quantity: One  
Part number: V628-650925-005  
Weight: 0.41 kilogram (0.9 pound)  
Stowage: Cargo bay  
Remarks: Common tool modified for EVA use.



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**A-27**

Item: EVA winch (I)

Quantity: Two

Part number: SED 33101570-305 (forward)

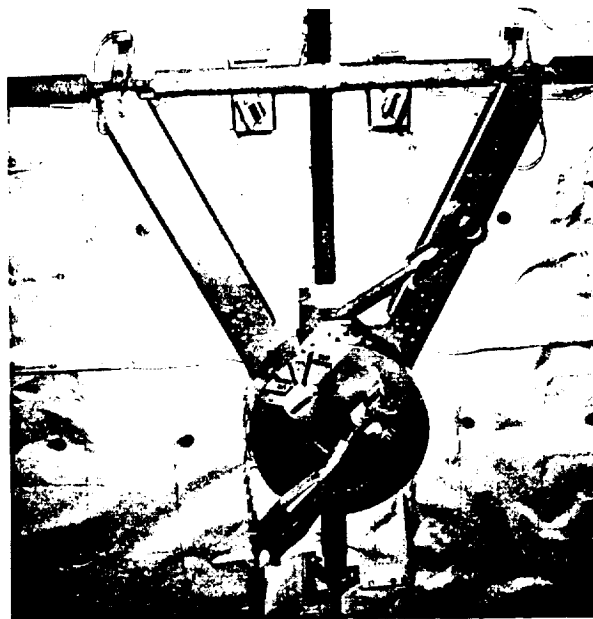
SED 33101570-307 (aft)

Weight: 10.9 kilograms (24 pounds) forward

9.5 kilograms (21 pounds) aft

Stowage: Cargo bay

Remarks: Mounted on forward and aft cargo bay bulkheads; may be relocated on orbit. Winch line is 7.3 meters (24 feet) long. Load limit of 265.45 kilograms (585 pounds) may be overridden.



**A-28**

Item: Winch rope reel (III)

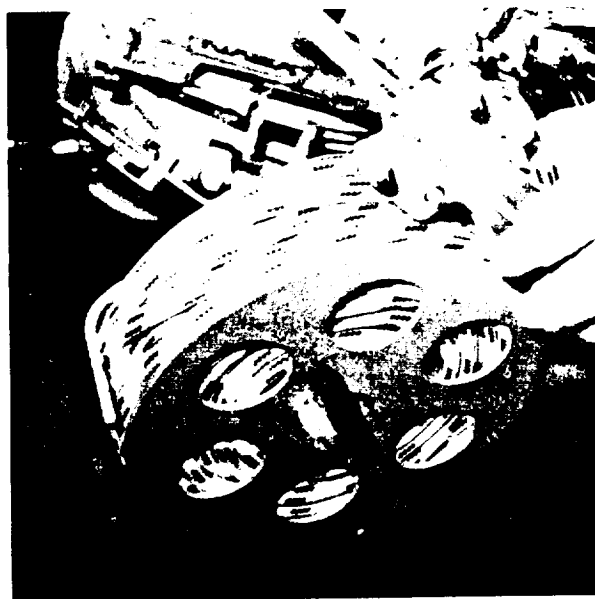
Quantity: One

Part number: SED 33102348-303

Weight: 3.67 kilograms (8.1 pounds)

Stowage: Cargo bay

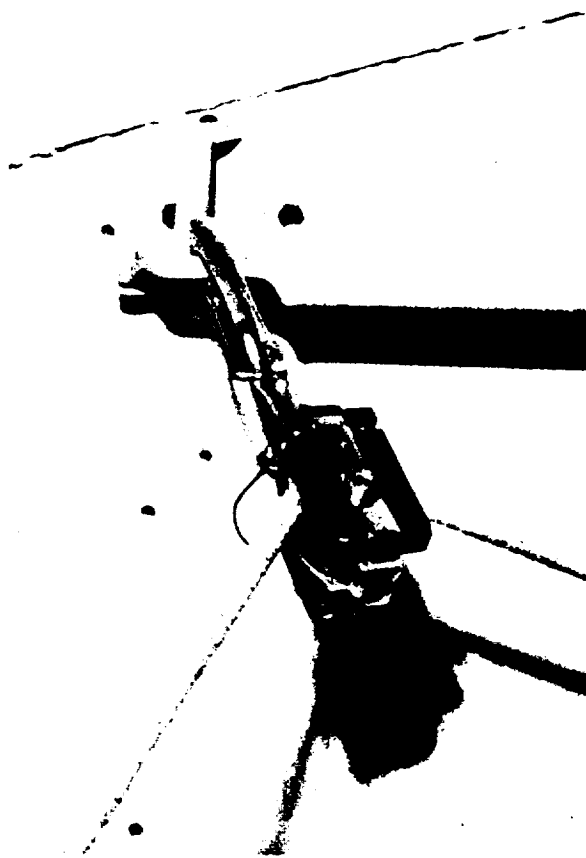
Remarks: Provides 24.38 meters (80 feet) rope to extend reach of cargo bay winch.



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**A-29**

Item: Snatch block (I)  
Quantity: As required  
Part number: SED 33102357-303  
Weight: 0.75 kilogram (1.66 pounds)  
Stowage: Cargo bay  
Remarks: Common marine device modified for  
EVA use. Used to route cargo bay winch line to  
support payload or Orbiter contingency tasks.



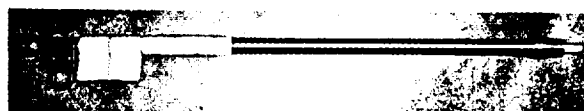
**A-30**

Item: 1/2-inch ratcheting box wrench (I)  
Quantity: One  
Part number: V628-650885-004  
Weight: 0.45 kilogram (1.0 pound)  
Stowage: Cargo bay  
Remarks: Common tool modified for EVA use.



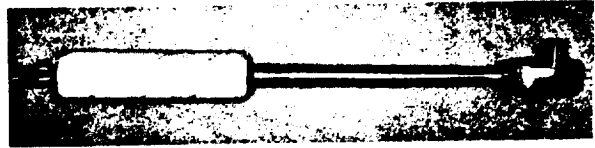
**A-31**

Item: 1/4-inch hex Allen, 19.5-inch drive extension (I)  
Quantity: One  
Part number: V628-650896-004  
Weight: 0.45 kilogram (1.0 pound)  
Stowage: Cargo bay  
Remarks: Extended Allen head wrench used with  
3/8-inch drive to perform Orbiter radiator drive  
disconnect task.



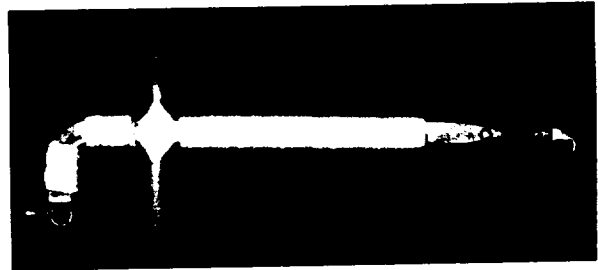
**A-32**

Item: 3/8-inch ratchet drive (I)  
Quantity: One  
Part number: V628-650881-001  
Weight: 0.36 kilogram (0.8 pound)  
Stowage: Cargo bay  
Remarks: Common tool modified for EVA use.  
Ratchet applies force only in clockwise direction  
(to loosen) and slips in counterclockwise direction.



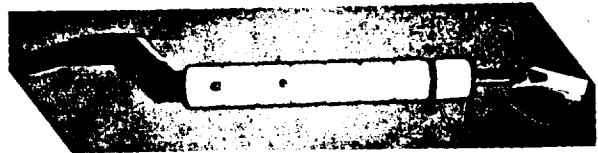
**A-33**

Item: Loop pin extractor (I)  
Quantity: One  
Part number: V628-650998-001  
Weight: 0.36 kilogram (0.8 pound)  
Stowage: Cargo bay  
Remarks: Used for removing loop pins from  
mechanisms to be disconnected by bolt removal.



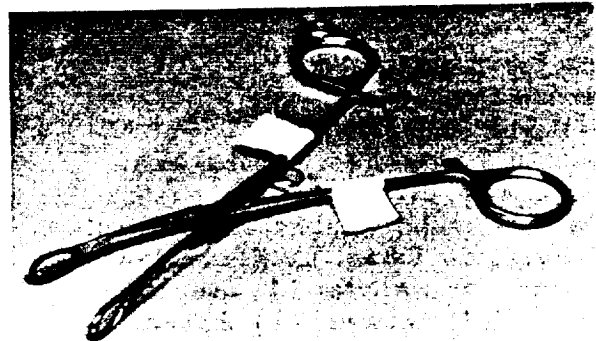
**A-34**

Item: Pry bar (I)  
Quantity: One  
Part number: V628-650990-005  
Weight: 1.45 kilograms (3.2 pounds)  
Stowage: Cargo bay  
Remarks: Specifically developed for centerline  
latches of cargo bay door; 58.42 centimeters (23  
inches) long.



**A-35**

Item: Forceps (I)  
Quantity: One pair  
Part number: V628-650887-001  
Weight: 0.09 kilogram (0.2 pound)  
Stowage: Cargo bay  
Remarks: Common medical instrument modified  
for EVA use in removing foreign objects from  
jammed mechanical systems.



**A-36**

Item: Cargo bay stowage assembly (toolbox) (I)

Quantity: One

Part number: V567-000002-002

Weight: 108.23 kilograms (238.6 pounds)

Stowage: Cargo bay

Remarks: Provides stowage location for EVA tools in cargo bay. Useful volume is 0.52 cubic meter (18.3 cubic feet), including dividers and cushions. Maximum weight of contents is 181.44 kilograms (400 pounds). Can be located in several locations along sill longeron, port or starboard side. Normally launched with portable foot restraints mounted at the bottom. Weight cited includes support assembly for mounting to Orbiter. Some locations allow lightweight support assembly, which is 53.07 kilograms (117 pounds) lighter.



**A-37**

Item: Provisions stowage assembly (IV)

Quantity: One set

Part number: TBD

Weight: TBD

Stowage: Cargo bay

Remarks: Developmental. Will provide as much as 0.40 cubic meter (14 cubic feet) stowage volume for EVA tools under the cargo bay liner within the forward 1.22 meters (48 inches) of the bay. Maximum weight of contents will be approximately 181.44 kilograms (400 pounds).

**A-38**

Item: Tube cutter (I)

Quantity: Two

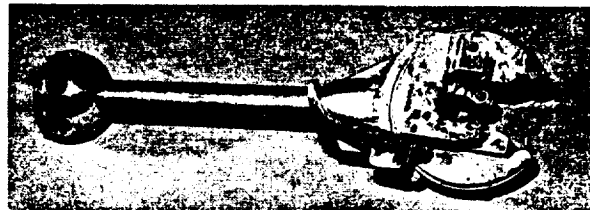
Part number: SED 33101368-301

Weight: 0.77 kilogram (1.70 pounds) each

Stowage: Cargo bay

Remarks: Similar to plumber's pipe cutter.

Designed for Inconel linkages of door drive system. Can cut tubes 1.27 centimeters (1/2 inch) to 2.54 centimeters (1 inch) in diameter.





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**A-39**

Item: Tape set (I)  
Quantity: One  
Part number: 10159-20004-01  
Weight: 0.38 kilogram (0.83 pound)  
Stowage: Cargo bay  
Remarks: Tool caddy containing twelve 15.24-centimeter (6 inch) strips of waterproof cloth duct tape used for restraining disconnect mechanisms or loose hardware.

**A-40**

Item: Velcro strap set (I)  
Quantity: One  
Part number: 10159-20006-01  
Weight: 0.82 kilogram (1.80 pounds)  
Stowage: Cargo bay  
Remarks: Tool caddy containing four 25.40-centimeter (10 inch) Velcro straps for use in restraining disconnect mechanisms or loose equipment.

**A-41**

Item: Trash container (IV)  
Quantity: One  
Part number: 10165-10065-01  
Weight: 0.45 kilogram (1.0 pound)  
Stowage: Cargo bay  
Remarks: Attaches to mini work station. Holds small, loose items.



**A-42**

Item: Payload retention device (I)

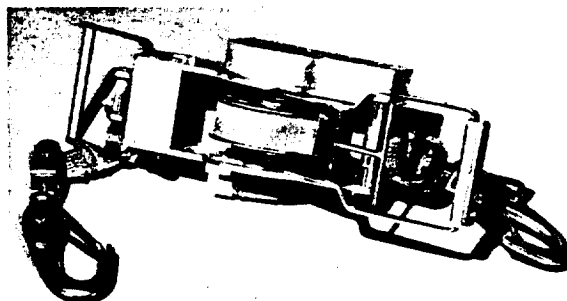
Quantity: Two

Part number: 10163-10063-02

Weight: 3.63 kilograms (8.0 pounds)

Stowage: Cargo bay

Remarks: Used to position and secure unlatched articles to mounting points. Maximum preload capable is 10 kilonewtons (2250 pounds). Distance between attachment points is 4.52 meters (14.83 feet) maximum.



## Appendix B - Acronyms and Abbreviations

ACS	attitude control system	MMS	Multimission Modular Spacecraft
AFTA	aft frame tilt actuator	MMU	manned maneuvering unit
ASE	airborne support equipment	MRS	module retention system
		MSFC	George C. Marshall Space Flight Center
B&W	black and white	MSS	module support structure
c	candle	MST	module servicing tool
C&DH	command and data handling	MWS	mini work station
CCTV	closed-circuit television		
CDR	Critical Design Review	N	newton
cm	centimeter	N/A	not applicable
CO <sub>2</sub>	carbon dioxide	NASA	National Aeronautics and Space Administration
ECS	environmental control system	NHB	NASA handbook
EKG	electrocardiogram	nom	nominal
EMU	extravehicular mobility unit		
EV	extravehicular	o.d.	outside diameter
EVA	extravehicular activity	OFT	Orbital Flight Test
		ORU	orbital replaceable unit
F	Fahrenheit		
FDF	Flight Data File	PDR	Preliminary Design Review
FSS	flight support station	PDU	power drive unit
ft	foot	PFR	portable foot restraint
		PGA	pressure-garment assembly
g	acceleration due to gravity	PIP	Payload Integration Plan
GFE	Government-furnished equipment	PLSS	primary life support system
GN <sub>2</sub>	gaseous nitrogen	POS	portable oxygen system
		psi	pounds per square inch
HGAS	high-gain antenna system	psid	pounds per square inch differential
hr	hour		
		rad	radius
ICD	Interface Control Document	ref	reference
in.	inch	RF	radiofrequency
IUS	Inertial Upper Stage	RMS	remote manipulator system
IV	intravehicular		
IVA	intravehicular activity	s	second
		SA	solar array
JSC	Lyndon B. Johnson Space Center	SAL	Scientific Airlock
		SAS	solar array system
K	Kelvin	SC&CU	signal conditioning and control unit
kg	kilogram		
kN	kilonewton	SMM	Solar Maximum Mission
		SMRM	SMM repair mission
lb	pound	SOP	secondary oxygen pack
LiOH	lithium hydroxide	ST	Space Telescope
		STS	Space Transportation System
m	meter		
MFR	manipulator foot restraint	TBD	to be determined
mm	millimeter	typ	typical

TV television

UHF ultrahigh frequency

V volt

W watt

WETF Weightless Environment Training  
Facility

## Appendix C - Bibliography

### I. BACKGROUND OF EVA CAPABILITY DEVELOPMENT AND EVA EXPERIENCE

1. NASA SP-138, *Gemini Summary Conference*, George E. Mueller et al., Manned Spacecraft Center, Houston, Texas, Feb. 1967, pp. 67-146. A series of five papers describing experience gained and lessons learned during Gemini Program EVA efforts.
2. JSC-09423, *Apollo Program Summary Report*, Lyndon B. Johnson Space Center, Houston, Texas, Apr. 1975. Includes descriptions of EVA hardware used during the Apollo Program, concentrating on the extravehicular mobility unit.
3. MSC-05878, NASA General Working Paper, *Extravehicular-Activity Experience in Manned Space Operations*, D. C. Schultz, Manned Spacecraft Center, Houston, Texas, Sept. 1970. Provides a summary of flightcrew operational experience gained during the planning and conduct of extravehicular activity through Apollo 12, including descriptions of equipment used.
4. AAS74-120, *Skylab Extravehicular Activity*, D. C. Shultz et al., paper presented to twentieth annual meeting of the American Astronautical Society, Los Angeles, California, Aug. 1974. Discusses the use of EVA techniques during the Skylab Program for accomplishing major mission objectives, and major and minor repair work outside the Skylab orbital workshop.

### II. SPECIFICATIONS AND DESIGN REFERENCES

1. SC-L-0002, General Specification: *Lighting, Manned Spacecraft and Related Flight Crew Equipment, Functional Design Requirements For*, Manned Spacecraft Center, Houston, Texas, July 1972. Establishes the minimum requirements for the application of illumination sources installed in manned spacecraft and aerospace vehicles. Document also establishes the general requirements for the measurement of brightness, contrast and brightness ratios, transmission, gloss, and stray light of panels and displays.
2. SC-M-0003, General Specification: *Markings, Labeling and Color, Manned Spacecraft and Related Flight Crew Equipment, Functional Design Requirements For*, Manned Spacecraft Center, Houston, Texas, Nov. 1971, and Amendment 1, July 1975. Provides basic design guidelines for marking, labeling, and coloring control and display panels and other crew equipment.
3. SC-E-0006, General Specification: *Manned Spaceflight Extravehicular/Intravehicular Activity Support Equipment, Functional Design Requirements For*, Manned Spacecraft Center, Houston, Texas, Dec. 1972. Establishes the requirements and criteria for the design of translation and mobility handholds, foot restraints, and tether hooks.
4. MSFC-STD-512A, MSFC Design Standard, *Man/System Requirements for Weightless Environments*, George C. Marshall Space Flight Center, Huntsville, Alabama, Dec. 1976. Defines man-system design requirements, guidelines, constraints, and criteria for IVA and EVA derived from Skylab Program experience; includes detailed anthropomorphic data.
5. JSC-08708, *Design Environments for Crew Systems Division Provided Space Shuttle GFE Hardware*, Crew Systems Division, Manned Spacecraft Center, Houston, Texas, Sept. 1975. Provides designers with environmental requirements, both natural and induced, for equipment to be flown aboard the Space Shuttle, for all phases of Shuttle flight.

### III. STS PLANNING, OPERATIONS, AND REFERENCE DOCUMENTS

1. *Space Transportation System User Handbook*, NASA, June 1977. Provides general overview and references regarding the STS, mission profiles, integration process, and requirements.
2. JSC-11802, *Space Transportation System Reimbursement Guide*, NASA, May 1980. Provides U.S. commercial and foreign STS users with cost data, reimbursement schedules, and rules and policies regarding standard and optional service costs, and shared missions, including example calculations.
3. JSC-07700, Volume XIV, Revision G, Shuttle Program Level II Program Definition and Requirements: Space Shuttle System Payload Accommodations, Lyndon B. Johnson Space Center, Houston, Texas, Sept. 1980. Describes all payload accommodations and defines physical, fluid, ECS, electrical, avionics, software, and environmental interfaces between the payload and the STS.
4. JSC-12770, *Shuttle Flight Operations Manual, Volume 15, EVA*, Crew Training Division, Lyndon B. Johnson Space Center, Houston, Texas (current issue). Contains functional descriptions of and operational procedures for all Shuttle EVA equipment and supporting Orbiter provisions. It is the prime source of detailed operational data on all EVA systems and hardware.
5. JSC-14363, *Shuttle/Payload Integration Activities Plan*, Shuttle Payload Integration and Development Program Office, Lyndon B. Johnson Space Center, Houston, Texas, Sept. 1978. This document defines the standard plan for the management and technical activities for integrated ground and flight operations of payloads using the STS, including the standard Payload Integration Plan (PIP) and its associated data requirements.
6. JSC-14029, *Shuttle Payload Standard Integration Plan for Deployable-Type Payloads*, Shuttle Payload Integration and Development Program Office, Lyndon B. Johnson Space Center, Houston, Texas, June 1980. Contains a boilerplate Payload Integration Plan (PIP).
7. JSC-14063, *Data Requirements for the Extravehicular Activity Annex, Payload Integration Plan Annex No. 11*, Shuttle Payload Integration and Development Program Office, Lyndon B. Johnson Space Center, Houston, Texas, Feb. 1981. Defines the design data, operational data, and documentation required for the payload user to prepare the EVA Annex to the PIP.
8. SD72-SH-0107, *Requirements/Definition Document, Crew Station and Equipment, Book 7*, Space Division, Rockwell International, Feb. 1976. An internally controlled, Rockwell International document which defines the requirements for the Orbiter crew station and equipment, including interfaces and supporting hardware for EVA. Specifies design criteria for Orbiter sharp edges, corners, and protrusion hazards.
9. NHB 1700.7A, *Safety Policy and Requirements for Payloads Using the Space Transportation System*, NASA, Dec. 1980. Establishes the safety requirements applicable to all STS payloads and their ground-support equipment. Defines hazards and measures to monitor, control, or inhibit them. For EVA, refers user to JSC-10615.
10. JSC-13830, *The Implementation Procedure for STS Payloads System Safety Requirements*, NASA, May 1979. Defines required safety analyses, data submittals, and safety assessment reviews and program milestones for implementing requirements of NHB 1700.7A.

## **Part II**

# **EVA Design Requirements**





## Part II

# EVA Design Requirements

### 1.0 INTRODUCTION AND DEFINITIONS

This part of *EVA Description and Design Criteria* contains details of the specifications for designing EVA interfaces and accommodations in payload designs. These requirements have resulted from application of the cumulative EVA experience in the Gemini, Apollo, and Skylab Programs to the Space Transportation System's generic capabilities and specific requirements. The guidelines and constraints presented in this document are primarily concerned with the safety of the crew and equipment and the design of EVA support equipment

and man-machine interfaces for crew operation in the zero-g environment.

The following sections describe controlled requirements and specifications and therefore the terms used must be specific also. The words "shall" and "must" express provisions that are binding. The words "should" and "may" express highly recommended but not necessarily mandatory provisions. The word "will" expresses a declaration of purpose or is used in cases where simple futurity is intended.

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## 2.0 DESIGN REQUIREMENTS

In considering an EVA mission from airlock egress through task completion and return to the cabin, payload designs should address the following:

- Airlock to payload access corridor
- Translation aids to worksites
- Crew and equipment safety
- Cargo transfer requirements
- Restraint provisions at worksites
- Visibility and lighting requirements
- Working volume requirements
- EV glove interface
- EVA tool design

### 2.1 Airlock to Payload Access Corridor

- Payloads will provide access to the EVA work area and to the components requiring service.

EVA crew transfer corridors and work areas must be compatible with overall dimensions and mobility volume requirements of the space-suited crewman and any hardware being transferred.

- The minimum translation corridor for EMU-suited crewmembers is a 102-centimeter (40 inch) circle for straight-line translation through hatches and tunnellike structures or for free floating without translation aids. A translation path requiring the EVA crewmember to use mobility aids (e.g., handholds, payload structures) is recommended to be not less than 109 centimeters (43 inches) in diameter to avoid crewman contact between EMU hardware and vehicle/payload structures (fig. II.2-1). Additional volume is required when other than straight-line translation is needed.
- Payloads will not preclude egress from the Orbiter airlock. A 1.22-meter (48 inch) diameter, clear envelope is required for airlock egress and outer hatch operation. Any payload or support provision located in the shaded areas of figure II.2-2 must be removable or jettisonable so that this area is available before committing to an EVA. Variations to these guidelines can be evaluated on an individual basis.

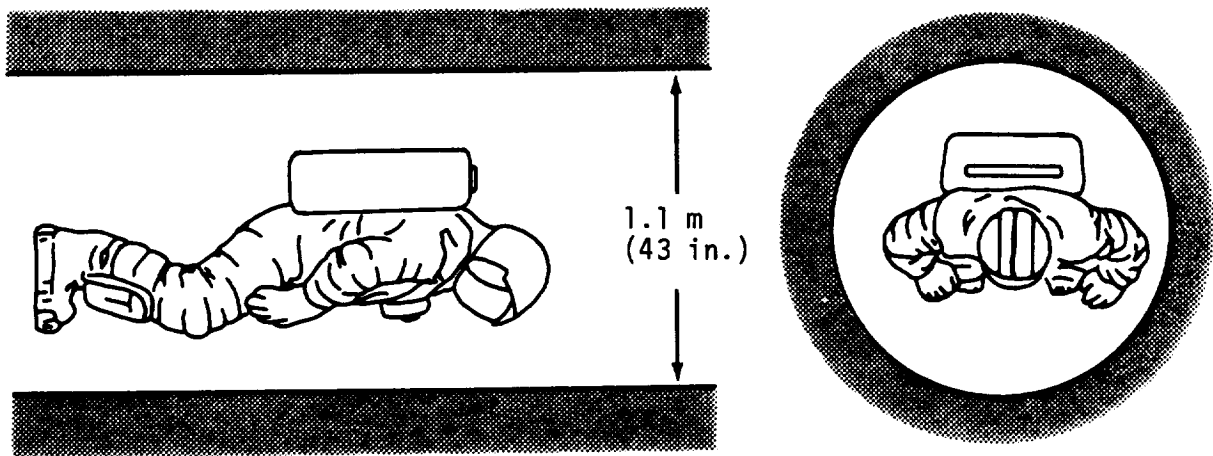


FIGURE II.2-1.—Envelope for handrail-assisted translation.

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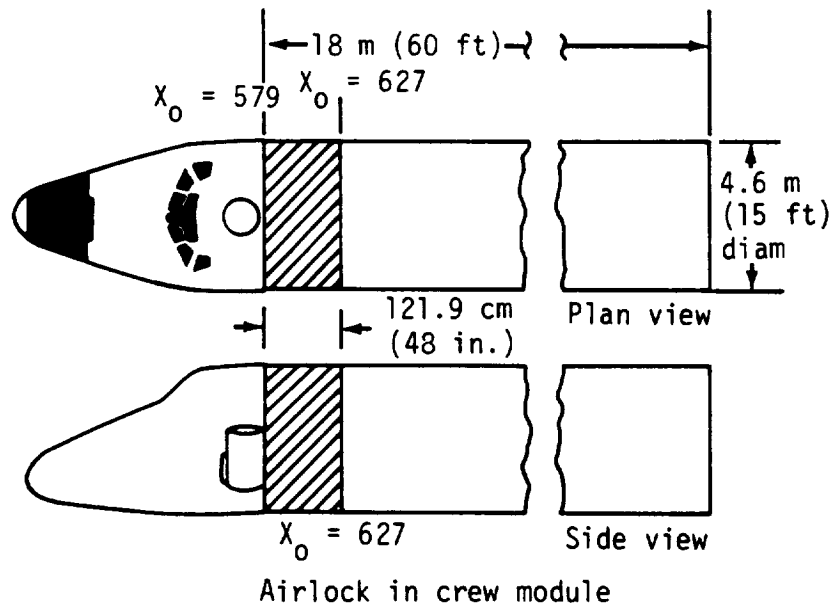



FIGURE II.2-2.— Reserved EVA envelope.

## **2.2 Translation Aids to Worksites**

- Crew translation provisions (e.g., handholds, handrails, mobility aids) in the payload planned work area shall be provided by the payload if requirements exceed those provided by the Orbiter-attached payload bay handrails.
- All payload handrails and handholds must meet the standardization requirements given in table II.2-1.
- Payload equipment or surfaces sensitive to inadvertent physical damage by an EVA crewman should be protected or located outside the EVA translation paths or EVA work areas.
- When properly designed and located, handrails and handholds can also provide local protection to payload components from damage by the crewman as well as convenient locations for temporary restraint of loose equipment. Some structural components that meet the requirements of table II.2-1 may double as translation or mobility aids if they are suitably identified. Orbiter handrails are painted yellow.
- The manned maneuvering unit will be used for translation to payloads that are not attached or berthed to the Orbiter.

TABLE II.2-1.— Handhold and Handrail General Design Characteristics

Design parameter	Design requirement/remarks
Cross section	<p>The EVA handholds/handrails will have a cross section which can be fabricated by forming standard 6061 aluminum tubing 28.6 mm outside diameter (o.d.) by 1.65 mm wall thickness (1.125 in. o.d. by 0.065 in. wall thickness), which gives 33 by 19 mm (1.38 by 0.75 in.).</p>  <p style="text-align: right;"> L                      W  33 mm                19 mm  (1.38 ±                (0.75 ±  0.060 in.)            0.060 in.) </p>
Length	The minimum grip length of handholds/handrails for EVA is 14.75 cm (5.81 in.).
Mounting clearance	The minimum clearance distance between the lower surface of the handrail/handhold and the mounting surface is 5.72 cm (2.25 in.).
Spacing for translation	For extravehicular translation, handholds/handrails shall not be separated more than 92 cm (36 in.). Maximum spacing of 61 cm (24.0 in.) is preferred.
Spacing for worksites	Handhold/handrail spacing shall not exceed 45.8 cm (18.0 in.) above or below the shoulder or 61.0 cm (24.0 in.) to the left or right of the body centerline when working in a foot restrained position.
Loading	Extravehicular handholds/handrails will be designed to a minimum crewman-induced zero-g design load of 832 N (187 lb) in any direction.
Tether attachment	EVA handholds/handrails will accommodate flight EVA tether hooks at a spacing not to exceed 73.7 cm (29.0 in.).
Tether attachment loading	Extravehicular handhold/handrail standoff tether points will be designed to a minimum crewman-induced zero-g design jerk load of 2553 N (574 lb) in any direction.
General location	<p>EVA handholds and handrails should be located to provide crewman protection from thermal, electrical, pyrotechnic, radiological, and electromagnetic equipment. Potentially dangerous equipment located within 30.5 cm (12.0 in.) of the translation route or worksite will be identified in accordance with SC-M-0003. Thermal control shall be compatible with temperature specifications of the assembly (PGA).</p> <p>Handholds used as ingress aids for foot restraints should be vertically oriented with respect to the foot restraint platform and should extend from 92 cm (36 in.) to 122 cm (48 in.) above it.</p>
Lighting	EVA handholds/handrails shall be illuminated in accordance with SC-L-0002.
Material	Handholds and handrails may be fabricated from metals. Other rigid, semirigid, or nonmetallic materials also may be used but must not be susceptible to brittle fracture.
Grasp surface	Handholds and handrails shall have a nonslip surface with no sharp edges or protrusions injurious to the crewman, EMU, or equipment.
Color	Lettering or numbering systems may be used to assist in rapid identification. Color shall be yellow from FED-STD-595A and minimize specular reflections in accordance with SC-M-0003.

## 2.3 Crew and Equipment Safety

- Payload designs will protect the crew from electrical, electronic, fluid, radiation, mechanical, chemical, and other hazards including inadvertent actuation of stored energy devices and pyrotechnics.
- No single failure or operator error shall result in damage to equipment or in the use of contingency or emergency procedures.
- No two failures and/or operator errors shall result in personnel injury or loss of life or prevent the safe return of the Orbiter vehicle.
- Payloads sensitive to EVA equipment effluent discharge should provide inherent self-protective features, provide protectors to be installed by the EVA crewman, or define EVA crewman operational constraints. The EMU discharges approximately 0.72 kg/hr (1.6 lb/hr) of oxygen and sublimates approximately 0.77 kg/hr (1.69 lb/hr) of water; the MMU discharges gaseous nitrogen. The EMU radiates 4 V/m at a distance of 1 meter in the UHF band (259.7 to 296.8 megahertz) when transmitting voice and 3 V/m in S-band (2250 megahertz) when the EMU-TV

is in operation. Maximum field strength occurs directly behind the EMU (for UHF) and above the helmet (S-band).

- A major safety concern in designing for Shuttle EVA is the compatibility of the Orbiter and payload systems/structures with the EV crewman's support equipment—particularly the life support systems and space suit components. Payload equipment, structures along translation routes, worksite provisions, and each equipment item requiring an EV interface either must be designed to preclude sharp edges and protrusions or must be covered in such a manner as to protect the crewman and his critical support equipment.
- Potentially hazardous items that would injure crewmen or damage equipment by entrapment, snagging, tearing, puncturing, cutting, or abrading are subjected to design constraints and evaluations to ensure hazard elimination or protection. Design criteria for equipment requiring an EV interface were developed for the Apollo and Skylab space programs. The criteria relative to sharp edges and protrusions are fully applicable to the Shuttle EVA payloads and are provided in table II.2-2. The area in which they are

TABLE II.2-2.— Edge, Corner, and Protrusion Criteria

(a) Edge and in-plane corner radii<sup>a</sup>

Application	Radius				Remarks
	Outer		Inner		
	cm	in.	cm	in.	
Openings, panels, covers (corner radii in plane of panel)	0.64 .30	0.25 .12	0.30 .15	0.12 .06	Preferred Minimum
Exposed sheet metal edges and flanges, latches, controls, hinges, and other small hardware operated by the pressurized-gloved hand	.10	.04	—	—	Minimum required to prevent glove snagging
Small protrusions (less than approximately 0.48 cm (3/16 in.)) on toggle switches, circuit breakers, connectors, latches, and other manipulative devices	.10	.04	—	—	Absolute minimum unless protruding corner is greater than 120°

<sup>a</sup>A 45° chamfer by 0.15 cm (0.06 in.) (minimum) with smooth broken edges is also acceptable in place of a corner radius. The width of chamfer should be selected to approximate the radius corner described above.

TABLE II.2-2.— Concluded

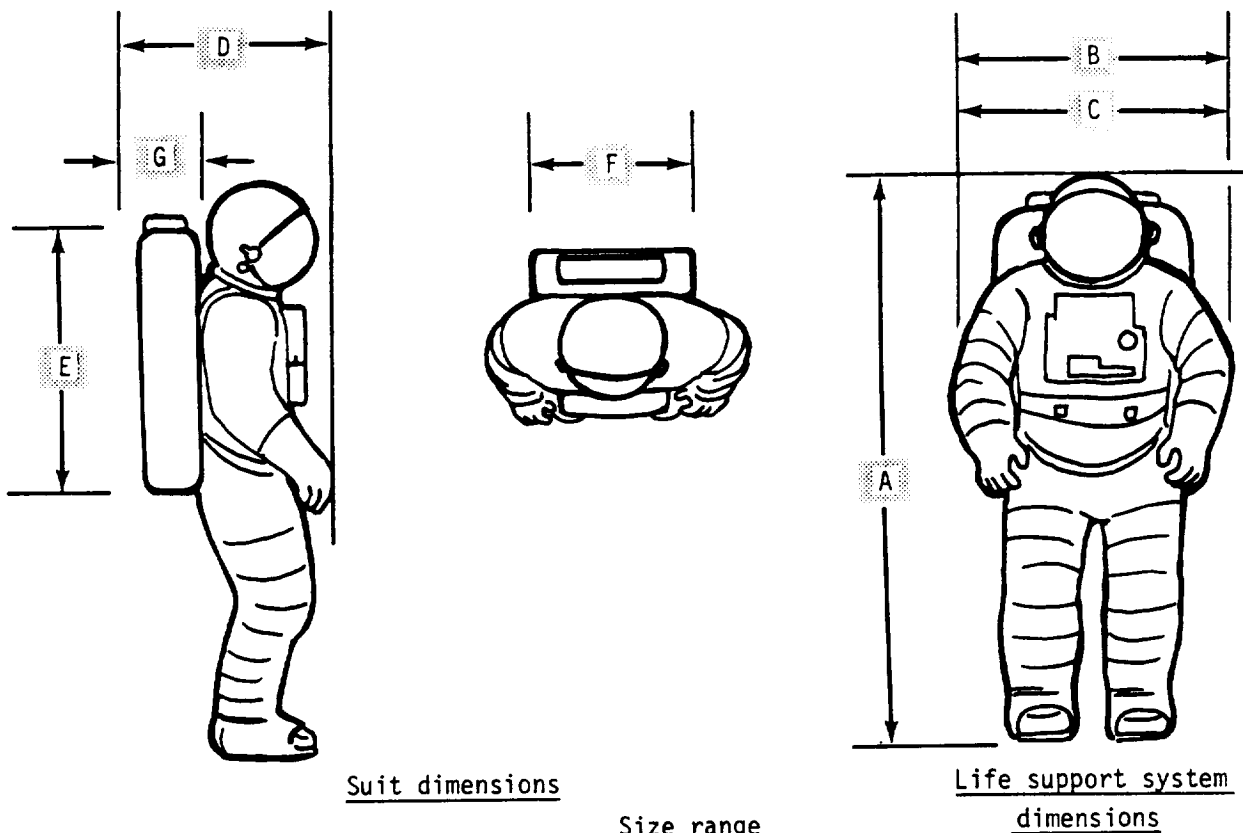
(b) Protrusions and outside corners

Application	Criterialremarks
Latching devices	<p>All latching devices shall be covered in a manner that does not allow gaps or overhangs that can catch fabrics or pressure suit appendages, or shall be designed in a manner to preclude the catching of fabrics and pressure suit appendages.</p> <p>All surfaces and edges shall be smooth, rounded, and free of burrs.</p>
Lap joints in sheet metal and mismatching of adjacent surfaces	<p>All surfaces shall be mated within 0.08 cm (0.03 in.) of flat surface at edges, or shall be butted or recessed. All exposed edges must be smooth and radiused 0.15 cm (0.06 in.) minimum (as above), chamfered 45°, or shall be covered with an appropriate material to protect EV gloves.</p>
Sheet metal structure, box and cabinet three-plane intersecting corners	<p>Spherical welded or formed radii are required unless corners are protected with covers.</p>
Screwheads, bolts, nuts, and nut plates, excess threads and rivets that can be contacted by crewman	<p>All screwheads and boltheads shall face the outside of the structure, if possible. Where nuts, nut plates, and threads are exposed, they shall be covered in a secure manner. Recessed heads or the use of recessed washers is recommended. Overall height of heads shall be within 0.32 cm (0.125 in.) or covered unless more than 7 head diameters apart from center to center. Height of roundhead or ovalhead screws is not limited. Screwheads or boltheads more than 0.64 cm (0.25 in.) deep must be recessed or be covered with a fairing, except those intended to be EVA crew interfaces.</p> <p>Rivet heads shall face out on all areas accessible to crewmen and shall protrude no more than 0.15 cm (0.06 in.) unless spaced more than 3.5 head diameters from center to center. In all exposed areas where unset ends of rivets extend more than 0.31 cm (0.12 in.), or 1.27 cm (0.50 in.) of unset and diameter if more than 0.31 cm (0.12 in.), a fairing shall be installed over them. This applies to explosive, blind, or pull rivets, etc. Unset ends of rivets must have edges chamfered 45° or ground off to a minimum radius of 0.15 cm (0.06 in.).</p> <p>A maximum gap of 0.05 cm (0.02 in.) will be allowed only between one side of a fastener head and its mating surface.</p> <p>Burrs must be prevented or eliminated. Use of Allen heads is preferred. Torque-set, slotted, or Phillips head screws must be covered with tape or other protective materials or be individually deburred before flight.</p>

to be applied is determined by applying the dimensional envelope of figure II.2-3 to the EVA worksite and translation routes. Sharp-

edge inspections will be performed on all payloads regardless of EVA intent.





	<u>Size range</u>				<u>dimensions</u>		
	<u>5th percentile</u>		<u>95th percentile</u>				
	<u>Female</u>		<u>Male</u>				
A - Height	171.5	(67.5)	191.8	(75.5)	E - Height	81.3	(32)
B - Maximum breadth at elbows (arms relaxed)	-	-	74.7	(29.4)	F - Breadth	58.4	(23)
C - Maximum breadth at elbows (arms at side)	-	-	67.1	(26.4)	G - Depth	17.8	( 7)
D - Maximum depth with PLSS/SOP	66.0	(26.0)	72.1	(28.4)			

All dimensions in centimeters with inches in parentheses.  
PLSS - primary life support system.  
SOP - secondary oxygen pack.

FIGURE II.2-3.— EMU dimensions.

#### 2.4 Cargo Transfer Requirements

Not all cargo transfer requirements may be satisfied by the RMS or by manual means. Factors such as package geometry, size, mass, transfer clearance envelope, or positioning requirements may render those means unsuitable for transporting replacement modules or servicing equipment from their launch stowage locations to the servicing

worksite. No specific criteria exist for the design of payload-peculiar transfer aids; figures II.2-4 and II.2-5 illustrate two concepts employed during the Skylab Program. The powered extendable boom was used to transfer a 56.7-kilogram (125 pound) film magazine, and the clothesline handled relatively small objects over what would have been a tedious manual translation route.

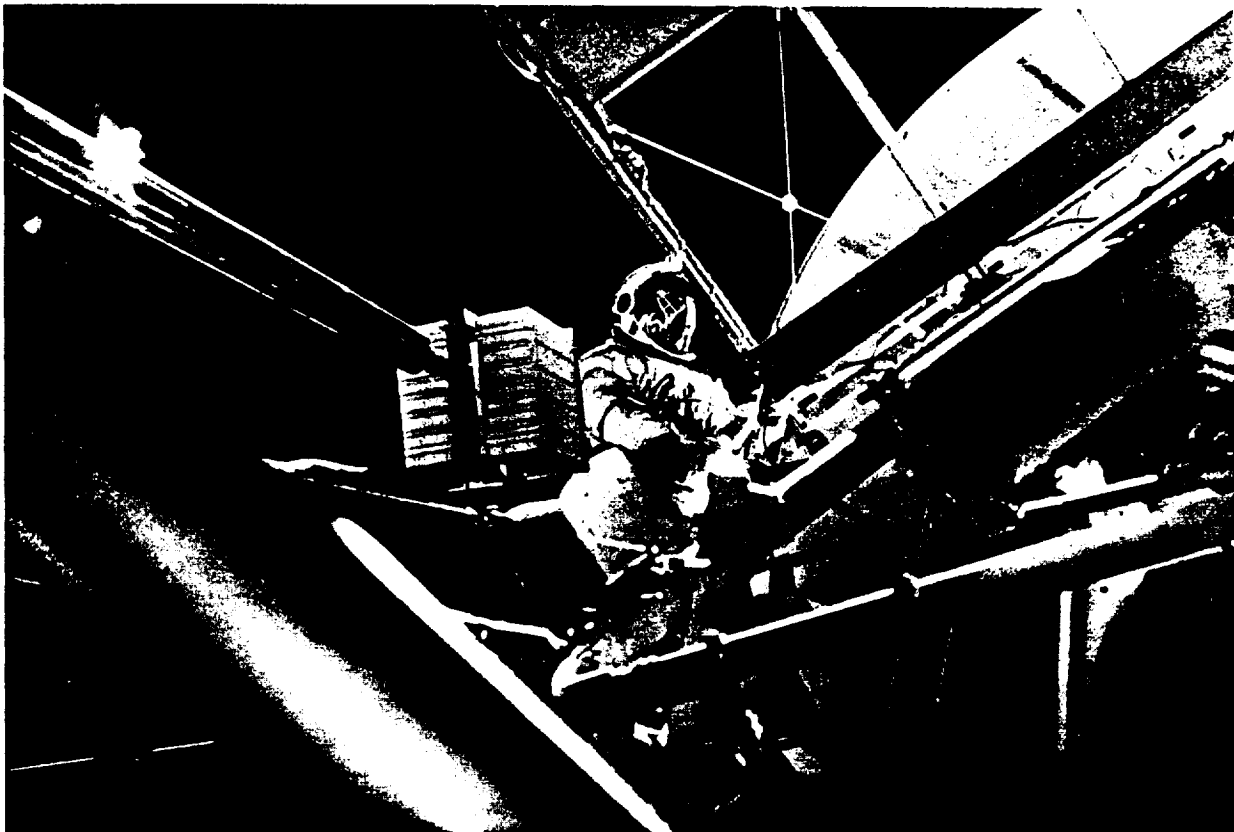


FIGURE II.2-4.— Powered extendable boom cargo transfer concept.

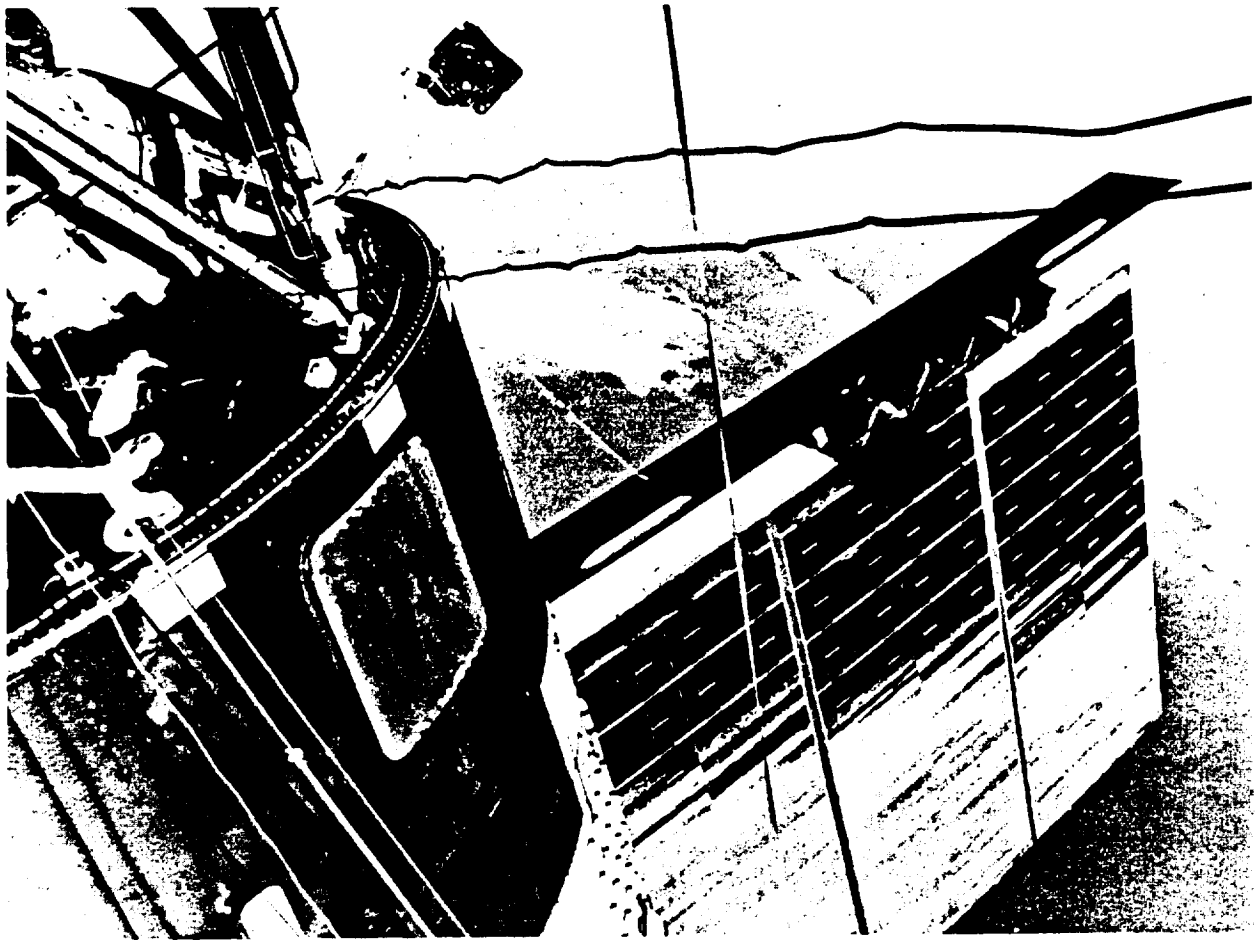


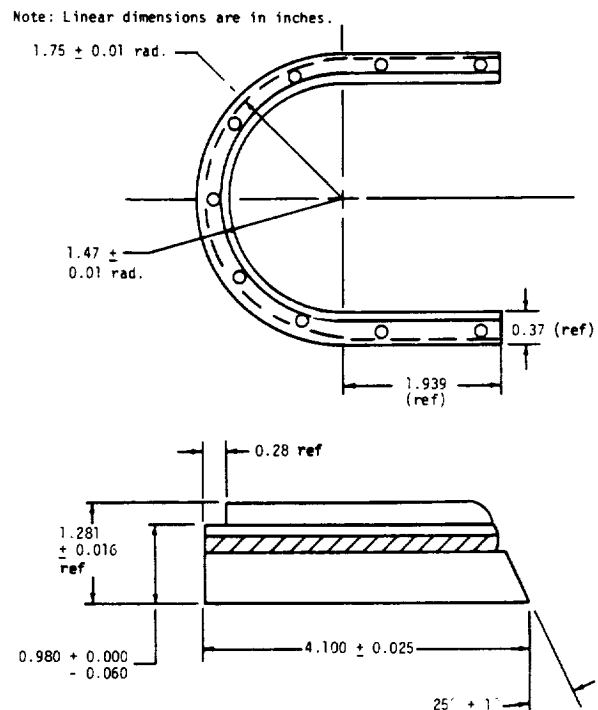
FIGURE II.2-5.— Clothesline cargo transfer concept.

## 2.5 Restraint Provisions at Worksites

- Payloads should utilize crew and equipment restraint provisions available from the STS inventory and provide interfaces for their attachment at the payload worksites.
- Except for MMU operations, EVA crewmembers will always be tethered to the Orbiter or payload.
- Proper restraint of the extravehicular crewmember at the worksite is mandatory to ensure successful EVA mission operations. Failure to provide adequate restraint can be the single most limiting factor of all EVA design elements, causing unnecessarily high workloads, early onset of crew fatigue, overloading of the life support system, and premature termination of the EVA. Techniques in the use of restraint provisions are an essential part of basic EVA training.
- Although the use of handholds and tethers (e.g., MWS work tether) may be adequate for low-force, short-time tasks such as inspections, monitoring, switch activation, etc., foot restraints have proven to be the most effective restraint system for extravehicular functions requiring moderate to heavy force applications and tasks involving medium to long-term positioning. The specifications for a foot restraint compatible with the standard EMU boot are given in table II.2-3. This is the same design used on the Orbiter airlock floor and on the portable foot restraint previously described.
- The foot restraint can be included in the design of the payload EVA worksite (fig. II.2-6) or an interface can be provided to accept the extension arm of the Orbiter PFR. If the PFR is not already included in the mission baseline, inclusion of it for the dedicated use of the payload will make it weight chargeable to the payload.
- All equipment transported or handled during EVA should have tether attach points. Any tools or equipment that are detachable from the vehicle structure must be tethered to the crewman, the vehicle, the MMU, or the payload whenever they are not securely stowed or installed. Even though EMU waist and wrist tethers can satisfy tethering requirements during



EMU BOOT

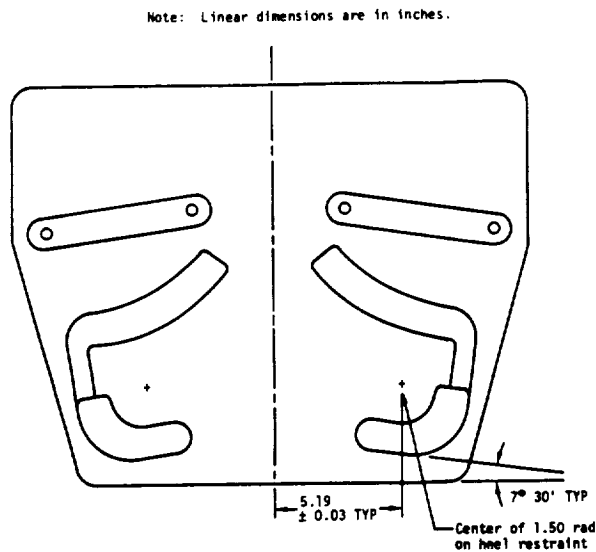


BOOT HEEL DETAIL

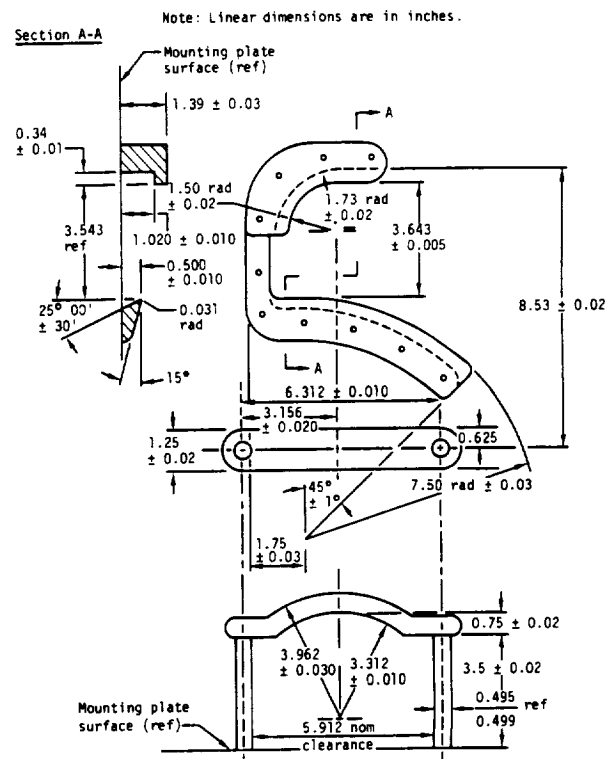
TABLE II.2-3.— EVA Foot Restraint General Specifications<sup>a</sup>

Design parameter	Design requirements/remarks
Mobility	EVA foot restraints shall maintain foot position to allow the crewman a complete range of motion (roll, pitch, yaw) within the constraints of the space suit.
Restraint spacing	<ul style="list-style-type: none"> <li>Center to center distance = 25.4 to 43.2 cm (10.0 to 17.0 in.).</li> <li>Center dimension shall be determined from analysis of the tasks to be performed.</li> </ul>
Load capacity	<ul style="list-style-type: none"> <li>Ultimate design load = 623 N (140 lb) minimum in tension and shear.</li> <li>Torsion = 203 N-m (1800 in-lb) minimum.</li> </ul>
Hazards	Foot restraints located within 30.5 cm (12 in.) of equipment where failure would cause injury to the crewman will be identified in accordance with SC-M-0003. Potential areas of damage to flight equipment by the crewman will also be identified.
Material	Metals shall be the primary material for foot restraint fabrication. Other rigid or semirigid materials may be used when warranted by design constraints. Materials must be approved in accordance with NHB 8060.1.

<sup>a</sup>Reference: 1. NASA General Specification SC-E-0006.  
2. ICD - HSD-3-0045-02-0.



TYPICAL LAYOUT



RESTRAINT DETAIL

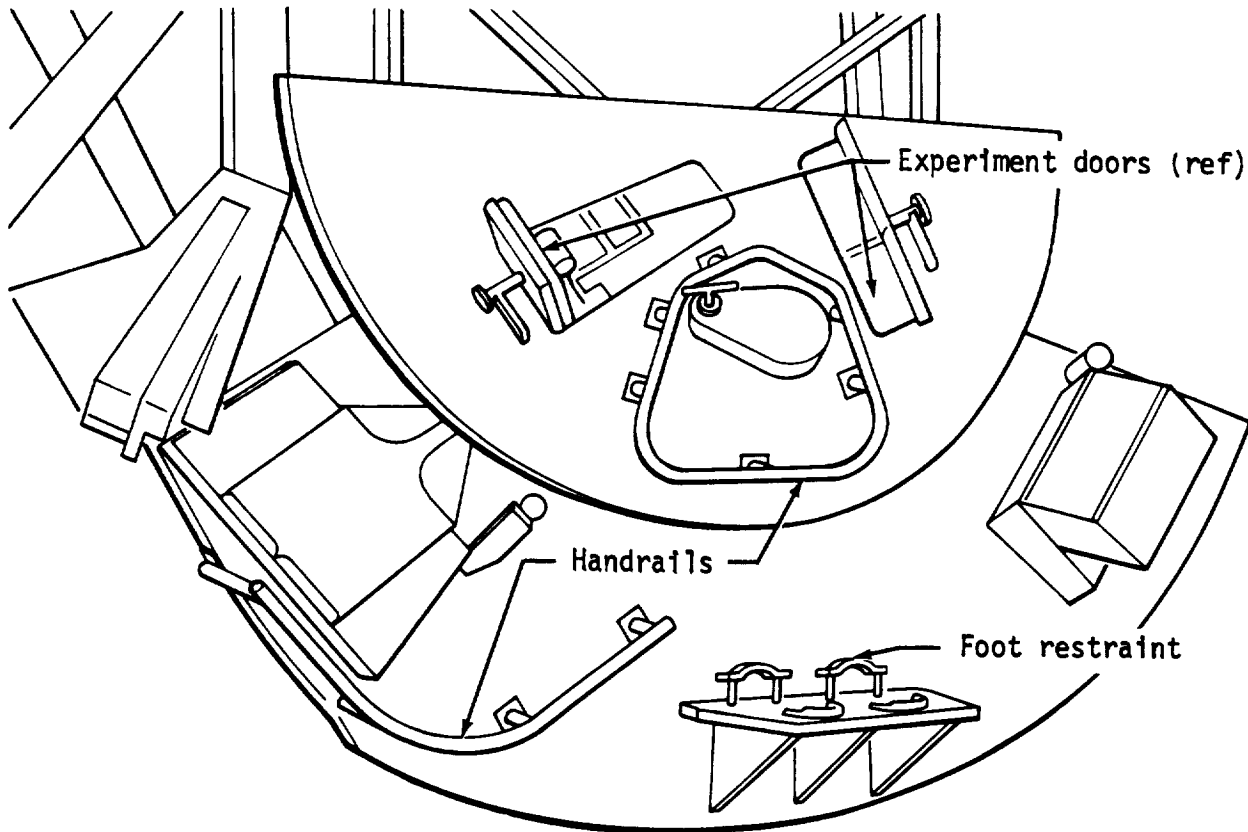


FIGURE II.2-6.— Skylab work station.

translation, a tether hook integral to the object or its transfer container also satisfies temporary stowage requirements at the worksite or along the translation route (fig. II.2-7). General specifications for the stowage hooks are shown in table II.2-4. Each payload EVA task requiring manipulation of loose articles should be studied individually to determine the type and quantity of restraints required.

- Where several worksites and various types of support equipment are included in a payload, a portable work station may be required. A portable work station would incorporate a base structure with foot restraints and attachment provisions for modularized support equipment. Factors to be considered in work-station design include launch and entry stowage, translation to worksite (RMS, MMU), attachment to the payload, and loads transmitted through the device to the payload by the crewman. All work-



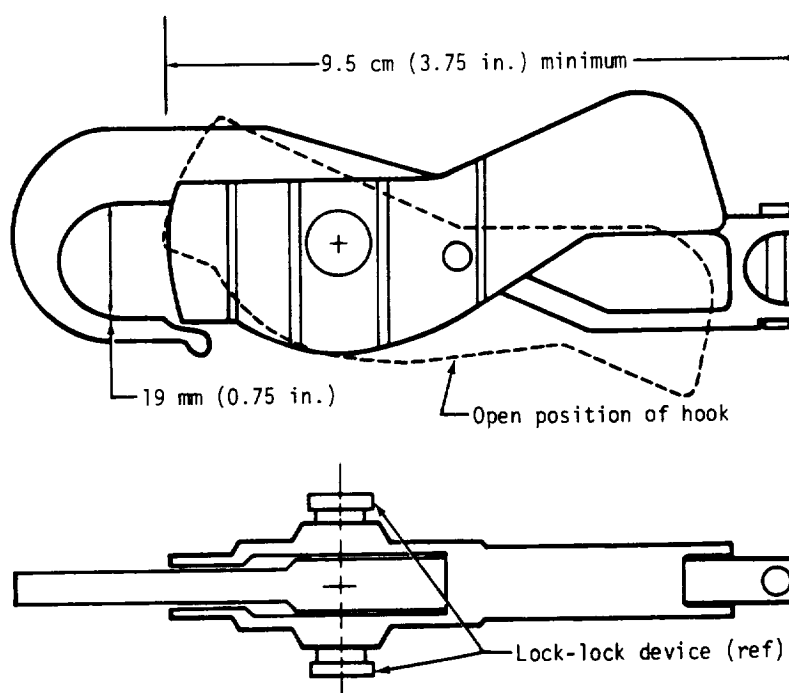
FIGURE II.2-7.— Tool bag with tether hook.

restraint/work-station designs must incorporate some type of ingress aid, such as an appropriately placed handhold, to assist the crew-

TABLE II.2-4.— EVA Equipment Tether Hook General Specifications<sup>a</sup>

Parameter	Design requirements/remarks
Dimensions	<p>Handle length shall be 9.5 cm (3.75 in.) minimum to fit in pressurized glove and allow hook to be clear for operation.</p> <p>Hook diameter recommended 19 mm (0.75 in.) minimum for attachment to Orbiter tether attach points.</p>
Design load limit	Dependent on intended use. Crewman safety tethers designed for 2610 N (585 lb) ultimate. Recommend 330 N (75 lb) minimum for equipment tethers.
Operation	Hook must allow one-handed operation by a suited crewman.
Safety	Hook should employ lock-lock feature such that no single inadvertent action could open hook.
Materials	EVA tether hooks will primarily be manufactured from metals.

<sup>a</sup>Reference: NASA General Specification SC-E-0006



man in maintaining body position until he has successfully ingressed the restraint. Experience has shown that a considerable amount of effort

can be wasted before the crewman begins an EVA task if the restraint provisions are not complemented in this manner (fig. II.2-6).

## 2.6 Visibility and Lighting Requirements

The lighting requirements for EVA can usually be satisfied by the STS through a combination of ambient solar illumination, permanently mounted lights, and portable lights. Requirements that exceed the lighting provided by the payload bay, RMS, and EMU helmet-mounted lights will have to be satisfied by payload-provided lights. The criteria can be found in Section 3 of MSFC STD 512A.

## 2.7 Working Volume Requirements

- EVA tasks that involve extensive body and arm manipulation will need a working envelope of approximately 1.2 meters (4 feet) (fig. II.2-8); the exact size will be dependent on the EMU dimensions and the type of task to be performed. Figure II.2-3 illustrates the dimensions of the EMU, to use in determining the volume

required to access a worksite. Access volume is not necessarily equivalent to required working volume; the latter also includes the factors of reach and force applications as well as the crewman's ability to see the task area. Adequate working volume therefore cannot always be specified and must be evaluated on a case-by-case basis.

In payload servicing operations that require reaching into an aperture, designers should position the equipment as close to the exterior surface as design will permit while allowing sufficient volume for access by the EVA glove and for crewman visibility. The minimum work envelope required for a gloved hand is shown in figure II.2-9. The 20-centimeter (8 inch) minimum aperture must be increased for operation of valves, connectors, and latches requiring torquing motions or heavy force application.

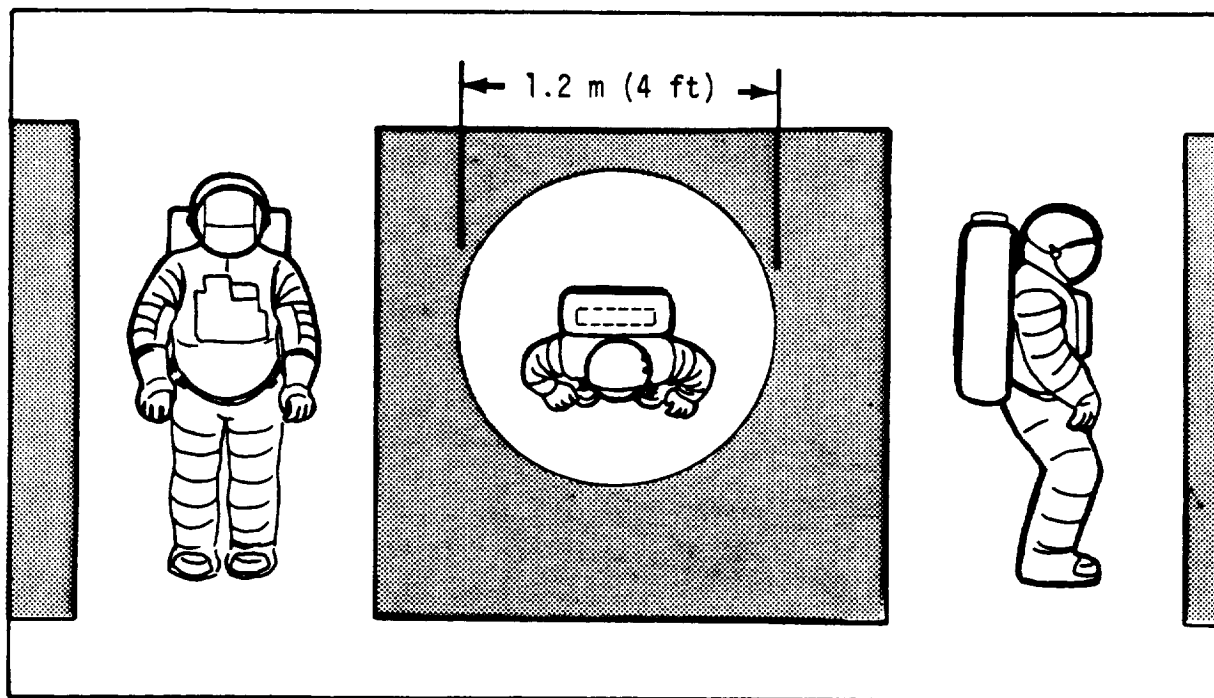


FIGURE II.2-8.— Recommended envelope for manipulative EVA tasks.



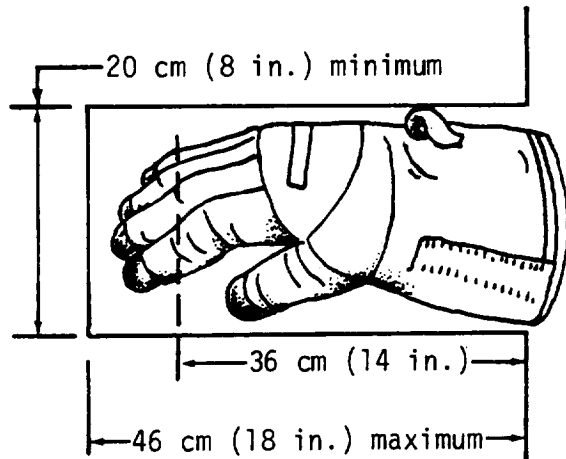


FIGURE II.2-9.— Work envelope for gloved hand.

## 2.8 Glove Interface

The EV glove assemblies are designed to allow the hand to function in an operational mode with a minimum of mobility restriction while satisfying contact temperature and pressure requirements. The pressurized gloves can be worn for periods of 7 hours without undue discomfort. The gloves also allow firm grasp retention of handholds, switches, tools, etc., for short periods without hand fatigue.

The gloves are designed to withstand contact temperatures of 386 to 155 K (235° to -180° F) with a contact pressure of 7 kN/m<sup>2</sup> (1.0 psi) without discomfort to the hand for as long as 0.5 minute. Thermal pads are provided to extend the contact temperature exposure time if necessary.

In designing payload interfaces for gloved-hand operations, compatibility of grasp surfaces must be considered. Conformal or oval handles are easier to grasp than cylindrical shapes; knurled knobs are better than smooth spheres; nonskid surfaces are preferred.

## 2.9 EVA Tool Design

Although the basic selection or design of EVA tools is entirely dependent on the nature of the task, several features are common to all successful EVA tool designs. These features are as follows.

- Grip size suitable for use with a pressurized EV glove
- Provisions for launch, entry, and temporary in-flight stowage
- Provisions for tethering while in use that satisfy zero-g tool management requirements
- Safety features to protect the EV crewman from inherent hazards

Since the functional design of the tool can vary greatly, no attempt is made here to provide more definitive specifications. Some examples of baselined tools, modified off-the-shelf to satisfy EVA requirements, are included in figure I.4-5. Figure II.2-10 illustrates the recommended standard EVA tool grip dimensions.

- EVA tool design should concentrate on gross motor motions. The mobility in the upper body

of the EMU lends itself to arm movements from either the shoulder or the elbow. Fine motor activity, particularly motions involving the gloved hand, should be avoided. Examples of motions which are very suitable to EVA are the cycling of a lever (ratcheting a drivescrew) and rotating a rotary actuator (airlock hatch). The likelihood of success of an EVA depends heavily on the workload of the crewmember, and using gross motor skills with relatively low loads is the place to begin.

- Tool use should require an actuation force of less than 89 newtons (20 pounds) or a torque of less than 15 N-m (11 ft-lb). Two hands should never be required for successful tool installation and operation, as all EVA operations are considerably easier when using one hand for additional restraint or position management.
- Power tools must meet the same design requirements as other handtools regarding operability. Using power tools to accomplish repetitive manual tasks such as disengaging captive fasteners on replaceable modules or operating mechanical drive systems offers enormous returns in reduced crewman time and effort, ease of operation, and, in some cases, increased reach from a given restrained position.

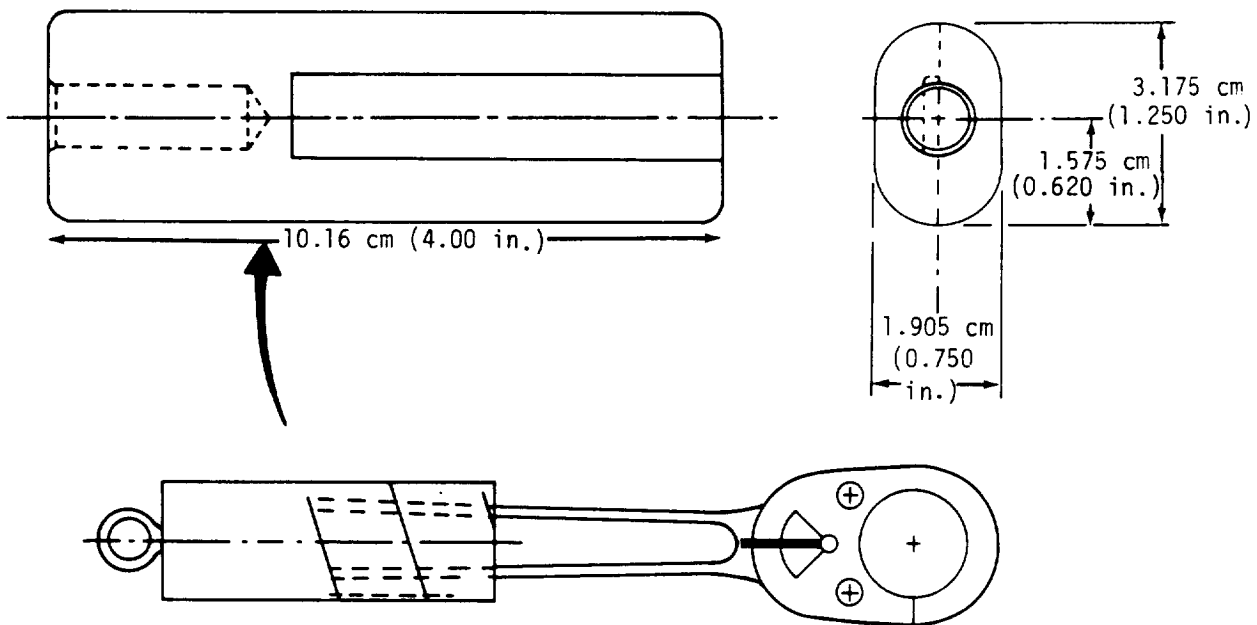


FIGURE II.2-10.— Recommended EVA tool grip dimensions.

## 2.10 Knobs, Switches, and Actuators

- Knobs, switches, lever and rotary actuators, and connector mate/demate devices should be designed to accommodate low-force, gross motor activity and provide positive stops and/or visual feedback to verify operation and prevent inadvertent selections. Ideally, simple or infrequently used devices should be designed to require force levels that can be satisfied without special restraint systems.
- A design that has been standardized for electrical connectors is shown in figure II.2-11. Overall dimensions vary with the design and performance requirements of the particular connector.

See appendix A for availability of NASA-procured connectors.

## 2.11 Access Doors and Panels

- Doors and panels to provide EVA access to payload enclosures should incorporate integral locking/unlocking mechanisms suitable for one-handed operation, incorporate some type of hold-open device, and be complemented by a suitably placed handhold for crewman position maintenance when opening and closing, and some means of visually verifying proper closing/latching.

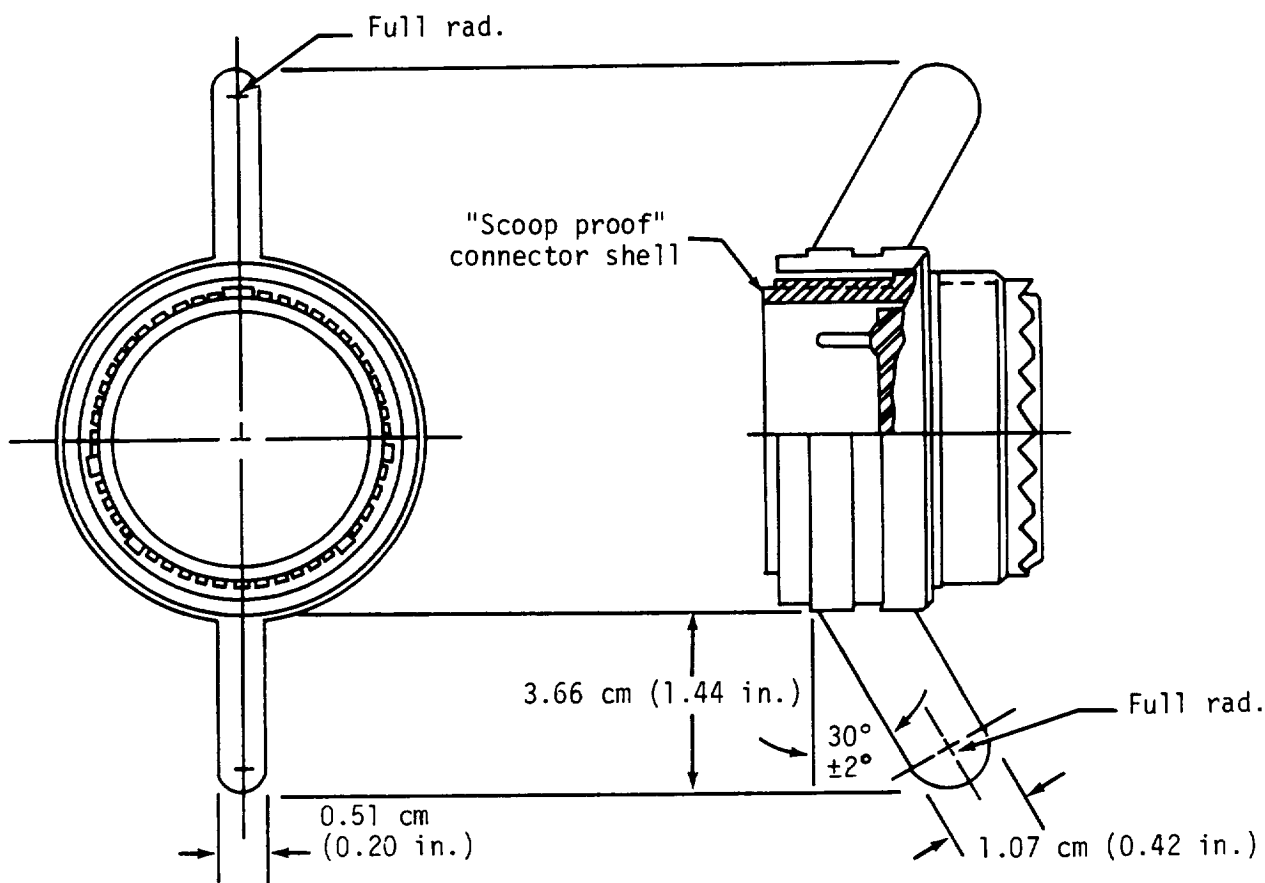


FIGURE II.2-11.— EVA standard connector.



### 3.0 SUMMARY

Although the criticality of an EVA task may be a constant, the payload designer can control the complexity of the task by incorporating standardized, proven techniques in the critical areas of access, restraint, and safety and in the design of the man-

machine interface. Applying the criteria in this document from the first stage of payload design will ensure cost-effective implementation of EVA requirements, maximum utilization of EVA capabilities, and enhanced probability of mission success.

PROCEEDING WITH CARE AND CAUTION



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